Monorail Global Scan and Assessment

November 2020

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BACKGROUND

The Maryland Department of Transportation (MDOT) is assessing the feasibility of a monorail along the I-270 corridor between I-370 and the City of Frederick. As part of this effort, MDOT performed a global scan of monorail systems and technologies. The scan included, to the extent possible, information on vehicle types, performance, stations, and costs of the monorail systems.

For the purpose of this assessment, a monorail system is defined as a driverless transit service on an elevated fixed guideway with a single rail on which vehicles will balance or be suspended, using electric motors for propulsion.

This document presents the results of the global scan and addresses the following questions:

- What are the characteristics of national and international monorails?
- What are some of the lessons learned from planning, constructing, and/or operating monorail systems?
- How do existing monorail systems compare to a potential I-270 monorail?

While the global scan included nearly 90 monorail systems, this white paper presents information on a smaller subset of eight (8) monorail systems, with a focus on urban/suburban commuter monorail systems located in areas comparable to the I-270 corridor. This global scan and assessment does not include people mover type systems intended for tourist attractions.

The eight monorail systems outlined in this paper were chosen primarily due to having three similar characteristics that are in line with what the I-270 corridor would require:

1. Built with the intention to serve as a transportation option for commuters;
2. At least three (3) miles long; and
3. Operates in both urban and suburban areas.

The remainder of this global scan and assessment provides:

- A brief summary of the status of monorails from a national and international perspective
- An overview of I-270
- Details on selected monorail case studies and their relevance to I-270
- Summary of findings
- Lessons learned

MDOT's Response to COVID-19

The COVID-19 public health crisis has dramatically impacted all Marylanders and required that we all make difficult adjustments in our daily lives. This has been a challenging and disruptive time. At MDOT, employees at all of our transportation business units are on the front lines of a statewide transportation system providing vital service to allow essential employees to get to work. As always, ensuring our employees' and customers' safety and the safety of all Marylanders is our top priority. Maryland's economy has taken a hit due to the impact of the COVID-19 pandemic. That impact has also affected the State's transportation system, with declines in use of the system, which has further reduced revenue to the Transportation Trust Fund. The full breadth of the COVID-19 pandemic's effects have yet to be realized, including impacts to state and local revenue and funding sources.

MONORAIL OVERVIEW

Monorail as a Transit Alternative

The first commercially viable monorail system, the Schwebebahn monorail in Wuppertal, Germany, opened in 1901 and is still in operation as part of Wuppertal's public transportation system. Today, monorails exist on every continent but Antartica and are predominantly in urban areas or attraction centers, with some monorails in suburban areas and at airports.

Despite over 100 years of history, monorail systems did not spread globally until the latter half of the 20th century and were disregarded as a viable transit-oriented congestion relief solution. The first modern-era straddle type (i.e., wrapping itself around or "straddling" the beam for stability) monorails began with the Alweg test track in Germany in the 1950s, leading to the first Disneyland monorail system in 1959. This in turn led to the first line haul, urban monorail system opening in 1964 (Tokyo's Haneda Line), which is still open and expanding.

Recently, several cities have begun heavily investing in monorails as key components of their transit services. South America and Asia are the two regions with the most developed monorail systems. The Sao Paulo, Brazil and Chongqing, China monorail systems are prominent examples of successful monorails—having two of the highest monorail ridership rates in the world. 90 monorail systems were identified as part of the global scan, including those that are operational, closed, under construction, or in the planning stages. At the time of this study, 57 systems were operational around the world, eight of which are in the United States. The majority of these monorails are the straddle beam type. Seventeen are under construction or in the testing phase, three are fully planned and pending construction, and nine are in the early-stage of conceptual planning. This list also includes four monorail systems that have closed since 2013 (Broadbeach and Sydney in Australia; Chiang Mai in Thailand; and Chester Zoo Monorail in England) due to low ridership, competing transportation systems such as light rail, system renovation costs, or inability to integrate with other existing transit options such as existing subway or metro heavy rail systems.

Monorails are not integrated with traffic and are almost exclusively separated by elevation, and/or separated through an independent right of way. Monorails often have slope or grade changes in their route which provide design flexibility—straddle systems have a maximum grade of ten percent, although six percent is the maximum grade typically used in practice. The rubber tire-to-concrete interface provides the friction necessary to reliably accommodate significant grades. They also have the same technological flexibility to operate driverless or via an in-car operator, similar to characteristics of light rail and metro systems (i.e. subway, elevated rail).

Monorails are typically seen as alternatives to subway or metro systems when the system performance (passenger transport capacity) dictates that the transit solution be grade-separated. Transit solutions that intermix with road traffic have limited capacity, whereas grade or guideway separated solutions (subway, elevated) inherently eliminate the constraints of mixed traffic.

Table 1 characterizes a recent monorail system across key variables and compares them to other familiar MDOT transit alternatives, namely light rail transit (LRT) and heavy rail/metro transit.

Table 1. Comparison of sample modern Monorail to Familiar Transit Services.

	Monorail (Sao Paulo)	Baltimore Light Rail	Purple Line Light Rail	Baltimore Metro	WMATA Red Line	MARC Brunswick Line
						
Current Operating Capacity (PPHPD)*	8016	2520	3448 (Planned)	7470	21,000	1534
Maximum gradient	6%	7.77 %	TBD (Under Construction)	4%	5%	4.5%
Train Capacity (people)	1002	420	431	996	1400	568
Vehicles per Train	7	3-unit train	5-car	6	8	4
Operating Speed (mph)**	25	22	TBD	30	28	34
Frequency (trains/h)	8	6	8	7.5	15	2.7

*Passengers Per Hour Per Direction ** Operating speed refers to the average operating speed between terminal stations, not the maximum speed.

Monorails in the United States

There are several monorail systems currently in operation in the United States, as shown in Figure 1. The most famous are at the DisneyWorld resort in Orlando, Florida and DisneyLand Amusement Park in Anaheim, California. The 14-mile system in Orlando provides transportation to the park's 50 million annual visitors, serving 150,000 daily passenger trips.

Figure 1: Map of Existing Monorails in the United States.

Las Vegas has planned an extension to add an eighth station to their monorail system, connecting to the Mandalay Bay Resort (Las Vegas Monorail, 2019). At least two additional major cities are considering monorail systems as part of transit expansions. LA Metro is currently considering a monorail as one of four options for the Sepulveda Transit Corridor Project in California (Hymon, 2019). Miami is also considering a monorail to link its downtown to Miami Beach. The Miami Metromover elevated people mover already operates and serves downtown via a loop around Miami and surrounding neighborhoods (Hanks, 2019). In addition, the Port Authority of New York and New Jersey (PANYNJ) plans to invest in a new AirTrain (monorail) system to replace the existing monorail at the Newark International Airport (Hutchins, 2019).

Monorail Features

Although there are both suspended and straddle monorails in service, the most common is the straddle. The suspended type has seen just a few iterations with no broad market support. Further reference in this paper is to the straddle type where not mentioned otherwise.

The most distinctive feature of the straddle beam monorail is the single beam that provides both vertical support as well as the lateral guidance and stability. The beams are typically concrete, but can also be steel. Steel construction is generally the prefered material for switches, although the Walt Disney monorail uses both steel and concrete for moving switch beams. Beam widths vary among the recent monorail offerings from 28 to 33 inches.

The monorail vehicles ride on rubber tires almost exclusively, especially those that carry significant passenger loads. The systems that support the movement of the monorail trains are typically all from the well developed transit industry including traction power, train control, door controls, air-conditioning, propulsion and braking. Aside from the vehicle interface between the train and the beam, the systems are not unique to monorail.

Below is a comparison of a typical light rail vehicle and a typical monorail supporting guideway in a sample elevated situation illustrating the beam interface to the train complete with emergency walkway. The overhead catenary is not shown for the light rail vehicle. As shown, monorail can have a lower profile and smaller footprint as compared to typical light rail.

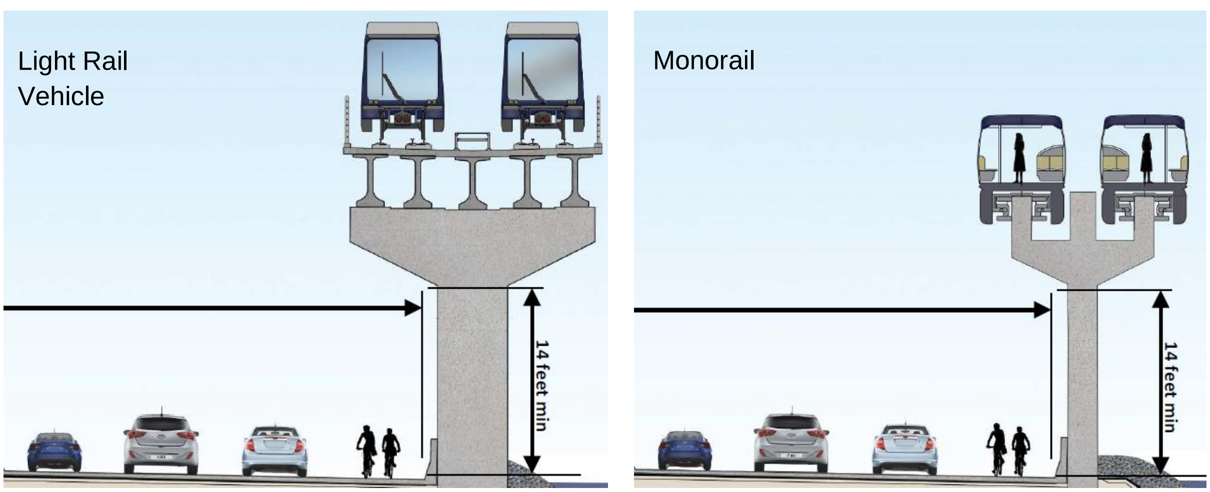


Figure 2: Monorail guideway comparison

Monorail Market 2020

The monorail market today is dominated by four major international companies: Bombardier, Build Your Dreams (BYD), China Railway Rolling Stock Corporation Limited (CRRC), and Hitachi. All these companies have significant interests in the U.S. in the supply of transit vehicles. Bombardier is active in the supply of steel wheel subway and intercity rolling stock, as well as rubber-tired People Movers. CRRC is constructing Metro cars for Chicago and Boston. Hitachi is building Metro cars for Miami and Baltimore. BYD is the only one of the four significantly invested in the U.S. transit bus market. BYD is not supplying any rail rolling stock in the U.S. All these companies are multi-billion dollar entities with resources that have demonstrated in recent years the ability to contract with and deliver large transit solutions to large cities.

What follows illustrates the monorail products being offered in the market today with the most recent examples potentially available for import to the U.S. Recent marketing material from each is included in the Appendix further illustrating the seriousness of these multi-national companies in the technology.

Bombardier Innovia 300 Monorail

Cities where in Service	Year in Service
Sao Paulo, Brazil	2014

Cities under Contract	Year in Contract
Riyadh, Saudi Arabia	2010
Bangkok, Thailand	2018
Cairo, Egypt	2019

BYD SkyRail

Cities where in Service	Year in Service
Shenzhen, China	2016
Yinchuan, China	2017

Cities under Contract	Expected Service Start
Guang'an, China	2020
Jining, China	2020
Shantou, China	2021
Salvador, Brazil	2022

CRRC Large Straddle Monorail

Cities where in Service	Year in Service
Chongqing, China	2011

Cities under Contract	Year in Contract
Wuhu[1], China	2018

[1] JV w/ Bombardier

Hitachi Large Monorail

Cities where in Service[1]	Year in Service
Daegu, South Korea	2015
Dubai, United Arab Emirates	2009

[1] Most Recent installations

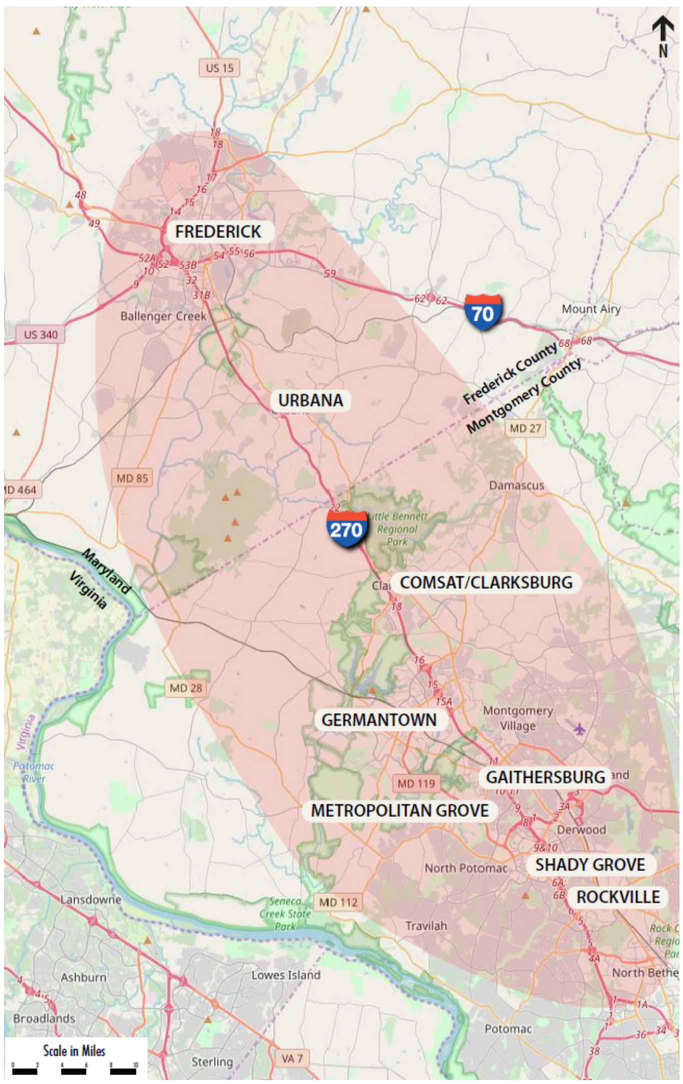
Cities under Contract	Year in Contract
Panama City, Panama	2018

I-270 OVERVIEW

I-270 is an interstate highway within the State of Maryland that covers a distance of nearly 35 miles from I-495 just north of Bethesda in Montgomery County, to I-70 in the City of Frederick in Frederick County. The area of interest is the 25 mile stretch of I-270 between I-370 near Shady Grove to the south and the City of Frederick to the north. This segment of I-270 traverses several urban and suburban areas as depicted in Figure 3.

The latest census data from the US Census Bureau (2019) indicates a range of population densities from 11,000 to 91,500 for the immediate vicinity of the I-270 corridor between the City of Frederick and Rockville. The highest concentrations of population are from Germantown south to Rockville and in the City of Frederick.

- Frederick 72,150 (2018)
- Urbana 11,000 (2017)
- Clarksburg 22,100 (2017)
- Germantown 91,500 (2017)
- Gaithersburg 68,300 (2018)
- Rockville 68,300 (2018)



MONORAIL CASE STUDIES

This section provides insight into the following eight (8) monorails from around the world, that illustrate various levels of relevance to I-270:

- Chongqing, China
- Daegu, South Korea
- Las Vegas, United States
- Mumbai, India
- Osaka, Japan
- Sao Paulo, Brazil
- Tama, Tokyo, Japan
- Wuppertal, Germany

These monorail systems were selected as case studies to provide a broad representation of monorail systems around the world. The selected locations include the world's first and oldest monorail system in Wuppertal, Germany, the world's largest monorail system in Chongqing, China, a fast-growing monorail system in Sao Paolo, Brazil, an underperforming monorail in terms of ridership, in Mumbai, India, and a domestic monorail in Las Vegas. All of the monorails, with the exception of the Las Vegas monorail, were built with the intention to serve as a line haul transportation option for commuters, are at least three (3) miles long, and operate in urban and/or suburban areas. The selected case studies are relevant to the I-270 corridor as they provide a range of comparative points of success and failure.

The Wuppertal system is included only to exemplify that, although the system is a unique one-off suspended monorail design, the proper planning and integration of the system, regardless of the technology's failure in the transit marketplace, has enabled its continuing success. The suspended type of monorail is not broadly available on the market today outside of recent installations in Japan and China, and vehicle replacement at Wuppertal.

The Las Vegas monorail is included as a best example of a monorail in an urban North American city. Here too is a one-off design based on an initial system placed into service five years prior. The proprietary design is unique and has been superseded by a design with greater performance, and currently available in the market.

For each monorail, the summaries below provide a high-level description, insight into their design and operations, and relevance to the proposed I-270 monorail project.

CHONGQING, CHINA

Description

Opened in 2005 and 2011 Lines 2 and 3, respectively, of the Chongqing Rail Transit system are the two monorail lines. The lines run through high-density commercial and residential areas crossing rivers and hilly to mountainous terrain. Line 2 as shown in green in Figure 5, connects Jiaochangkou to Yudong. Line 3, shown in dark blue connects Yudong to Jiangbei Airport (with a single station branch line from Bijin to Jurbena).

Years Open: 2005, 2011

Length: 19.4 miles, 41 miles

Number of Stations: 25, 45

Ridership (2015): Daily: 234,200, 682,800
Annual: 94 million, 250 million

Similarities to I-270

Similar length. The distance of the Chongqing monorail lines individually is similar to the total length of the I-270 study area

Differences to I-270

Significantly larger population. Chongqing has a population of approximately 30.5 million people.

Denser urban environment. Segments of the monorail are in much more urbanized areas where it has been built to pass through buildings.

Significant topographical barriers. Chongqing region is mountainous; the monorail lines traverse significant elevation gains and cross rivers.

Design & Operation

Speed: 50 MPH (maximum)

Travel Time: 27 minutes, 20-31 minutes

Headway: 3 -10 minutes**,** 12 minutes

Cost: Construction of Line 3: $2.1 billion USD.

Operating Expenses: No maintenance and operation costs publicly available.

Number/Type of Vehicles: 76 total cars arranged into four-car trains with a double axel bogie track

Infrastructure: Straddle-beam

Technology: Hitachi, DC: 1,500V electrical system, variable-voltage/variable-frequency (VVVF) traction inverter control unit, and ATP two-man operated operating system.

Fare Structure: Distance based: single-trip ranging from $0.28-$1.40 USD (2-10 Yuan)

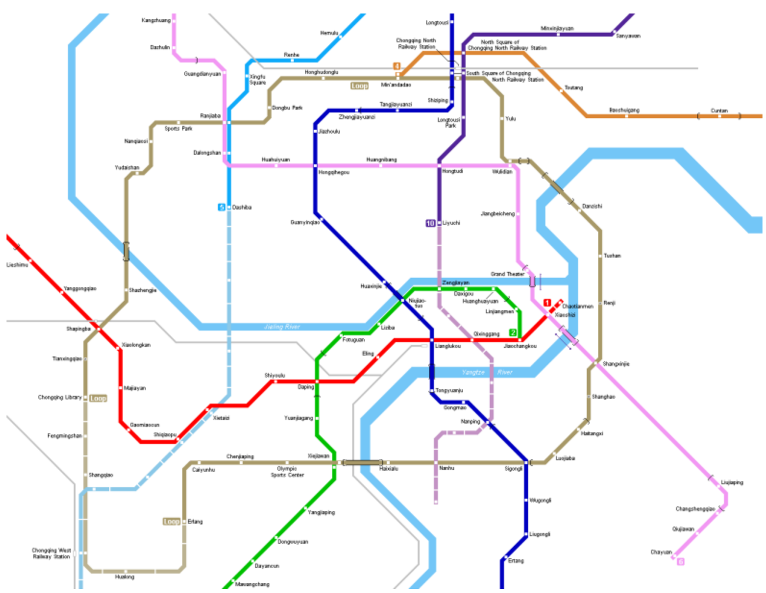


Figure 5: Chongqing Rail Transit Map. Line 2 (Green) and Line 3 (Dark Blue) Source: Urbanrail.net

DAEGU, SOUTH KOREA

Description

Line 3 of the Daegu Metro System is the 14.9-mile monorail located in Daegu, South Korea, that serves KNU Medical Center to the northwest to Yongji Station in the southeast of Daegu. This is a very high-density urban area.

Year Open: 2015

Length: 14.9 miles

Number of Stations: 30

Ridership (2017): Daily: 74,031

Similarities to I-270
Significant suburban commuter ridership. Park and ride lots at monorail station and transfers to other metro lines.

Differences to I-270
Larger population. Daegu metropolitan region: 5 million people **Significant topographical barriers.** Runs across two special bridges that cross bodies of water. **Denser urban environment.** Line 3 passes through the center of the city and provides direct access to central business district.

Design & Operation

Speed: 20-45 MPH (range of standard operating speeds)

Travel Time: 50 minutes (full length)

Headway: 8 minutes

Cost (2015): Construction: $792 million USD

Number/Type of Vehicles: 28 Hitachi monorail sets with 84 cars

Infrastructure: Straddle-beam

Technology: Digital Automatic Train Protection (ATP)/Automatic Train Operation (ATO)/ Automatic Train Supervision (ATS) driverless system and two closed-circuit surveillance cameras.

Fare Structure: Trip based: $1.17 USD/ticket (can be used between any two stations)

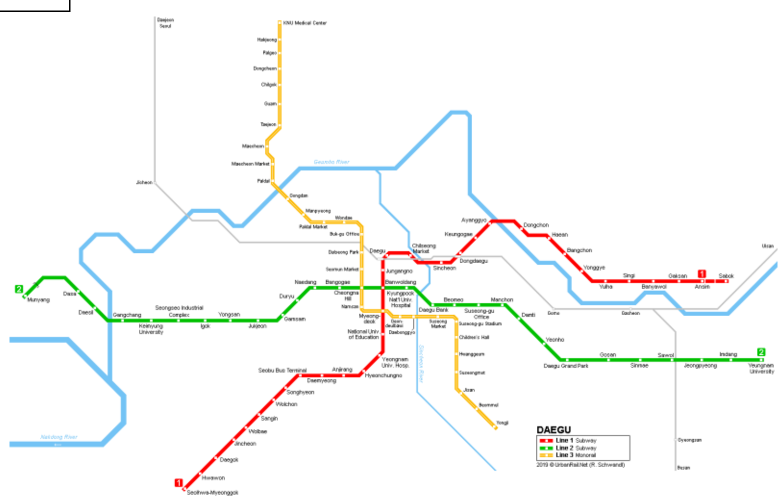


Figure 6 Map of Daegu Metro System Line 3 (Yellow) monorail. Source: Urbanrail.net

LAS VEGAS, UNITED STATES

Description

Located along the Las Vegas Strip, the 3.9-mile monorail system runs behind the casino hotels serving both residents and visitors to The Strip. The Strip is a high attraction area that the monorail began serving in 1995, operating between the MGM Grand and Bally's. In 2002 the monorail was reconstructed to go from two to seven stations. The system reopened in 2004 and now runs from the MGM Grand to the Sahara as pictured in Figure 7. A further expansion is planned.

Year Open: 1995

Length: 3.9 miles

Number of Stations: 7 (8th planned)

Ridership (2016): Daily: 13,500

Annual: 2.9 million

Similarities to I-270

Similar Population. Las Vegas: 650,000 people

Similar topography. Las Vegas is relatively flat.

Differences to I-270

Significant visitor/tourist ridership and "off-peak" travel. Peak hours on the monorail differ from traditional working hours. Many employees who commute their first/last miles on the monorail do so at many different times of day. Visitors are a targeted audience to ride the monorail.

Design & Operation

Speed: 50 MPH (maximum)

Travel Time: ~ 15 minutes total length

Headway: 4-8 minutes

Cost (2016): Construction: $350 million USD

Operating Expenses: $38.7 million USD

Number/Type of Vehicles: 36 Bombardier Innovia 200 cars monorail fleet with nine trains with four cars each.

Infrastructure: Straddle-beam, Von-Roll

Technology: Bombardier Trains

Fare Structure: Trip based: $5/ride (visitors) $1/ride (local residents) Unlimited daily and weekly passes available.

Figure 7 Map of Las Vegas Monorail. Source: MapaMetro

MUMBAI, INDIA

Description

The Chembur-Wadala-Jacob Circle corridor is the only monorail line in Mumbai. The line is made up of two phases opened in 2014 and 2019, respectively, and runs a total of 12.1 miles connecting urban to suburban areas.

Year Open: 2014, 2019

Length: 5.5 miles, 6.6 miles

Number of Stations: 17

Ridership (2019): Daily: 17,000, > 5,000

Similarities to I-270
Connects suburban and urban areas. Attempts to connect sprawling suburban areas to denser urban areas and job markets.

Differences to I-270
Significantly more densely populated. **Other transportation options above capacity.** Has existing transit services that are working beyond capacity. Its suburban rail network carries more than 8 million passengers per day and the bus services in the city are crowded and slow due to congestion.

Design & Operation

Speed:19 mph (avg.) to 50 MPH (max.)

Travel time: 42 minutes total length

Headway: 3-15 minutes

Cost: Construction $501.9 million USD

Operating Expenses:

Number /Type of Vehicles: 15, 4 (expected 17 trains by 2021)

Infrastructure: Straddle-beam

Technology: Alweg Technology

Fare Structure: Distance Based

0-1.86 miles (0-3km) $0.14 USD

1.86-7.45 miles (3-12 km) $0.28 USD

7.45-11.18 miles (12-18 km) $0.42 USD

11.18-14.91 miles (18-24 km) $0.56 USD

Figure 8. Map of Mumbai Monorail Source: monorails.org

OSAKA, JAPAN

Description

Open in 1990, the 17.4-mile monorail in Osaka serves an urban area that runs through suburbs to Osaka Airport connecting six cities.

Year Open: 1990

Length: 17.4 miles

Number of Stations: 18

Similarities to I-270

Connects suburban and urban areas. The Osaka monorail connects suburban areas to each other and the central Osaka districts.

Similar length. Before the Chongqing monorail was built, the Osaka monorail system was the largest in the world. There are not many long-distance monorail systems around the world, but the long, inter-suburban length is similar to the I-270 corridor.

Differences to I-270

Significantly larger population. Osaka: 2.7 million people.

Denser urban environment. The Osaka monorail is the second largest in the world, but it has many stops to match the urban density. There is a stop, on average, every half mile.

Transit-oriented development patterns. Japan has a meticulous national rail system, and local cities and regions have their own even more robust transit systems. Citizens do not need to be convinced to change their travel mode to train/monorail, which they would for an I-270 monorail.

Ridership (2017): Daily: 131,479, Annual: 44.5 million

Design & Operation

Speed: 45 MPH (maximum)

Travel Time: 36 minutes (entire route)

Headway: 4-8 minutes

Cost (2016): Construction Cost: $120 million USD per Kilometer

Operating Expenses – approximately $616,000 USD annually

Number/Type of Vehicles: Hitachi four-car trains

Infrastructure: Straddle-beam

Technology: Alweg-Hitachi, 1500 V electric

Fare Structure: Distance based: $1.86 - $5.11 USD (0.75 miles -13 miles)

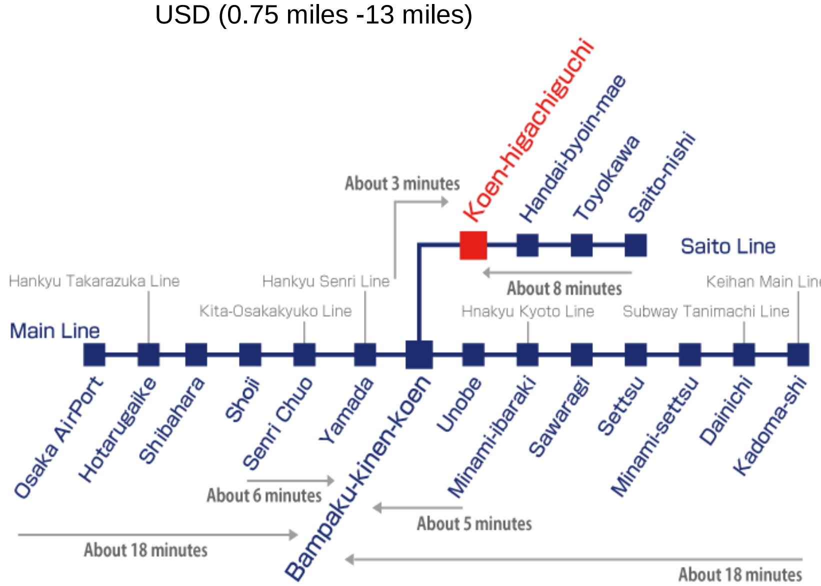


Figure 9: Osaka monorail. Source: minpaku.ac.jp

SAO PAULO, BRAZIL

Description

Open in 2008, the 4.7-mile monorail runs through high density urban areas. The line serves ten stations between Vila Prudente and Vila União. Once completed in 2021 it will be approximately 17 miles long and serve 18 stations.

Year Open: 2008

Length: 4.7 miles

Number of Stations: 10

Ridership (2021): Daily 500,000 estimated once fully completed

Similarities to I-270
Multimodal regional connectivity. The existing, and proposed, monorail lines in Sao Paolo are part of the larger subway system and act like an extension of the (heavy) metro rail.

Differences to I-270
Significantly larger population. Sao Paulo region: nearly 20 million people.
Denser urban environment. While shorter in distance, Sao Paulo's Line 15 monorail will have far more stops than the one would along I-270.

Design & Operation

Speed: 50 MPH (average)

Travel Time: 12 minutes (50 minutes end to end once completed)

Cost: Construction $1.6 billion USD (estimated for the entire project)

Number/Type of Vehicles: 54 seven-car Bombardier Innova 3000 trains

Infrastructure: Straddle-beam

Technology: CITYFLO 650 automatic train control

Fare Structure: Trip based: $1.03 USD base fare (one trip, any distance)

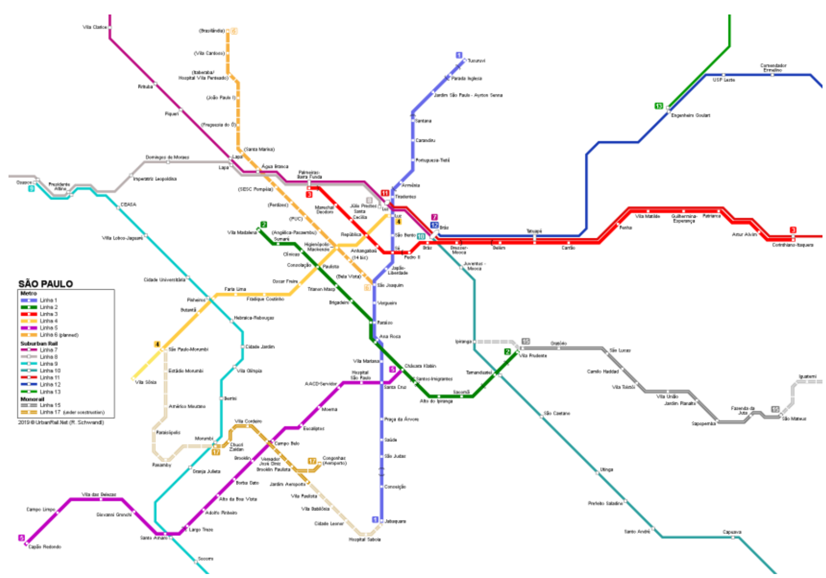


Figure 10: Map of Sao Paolo Metro System. Line 15 (Silver), an extension of Line 2 (Green), is the existing Monorail. Source: Urbanrail.net

TAMA, TOKYO, JAPAN

Description

This two-phased ten-mile monorail system (shown in orange in figure 10) was first opened in 1998 with phase 1 serving Kamikitadai to Tachikawa-Kita. Phase 2 was opened in 2000 continuing the line to Tama-Center. The monorail serves the southwestern Tokyo suburbs and connects private and state-owned railways to reach the outer suburbs to the urban core of Tokyo.

Year Open: 1998, 2000

Length: 10 miles

Number of Stations: 19

Ridership: Daily: 120,000 Annual: 50.5 million

Similarities to I-270

Connects suburban and urban areas. Serves southwestern Tokyo suburbs and Tama Toshi and connects to private and state-owned railways to reach the outer suburbs to the Tokyo urban core.

Similar population. The Tama suburban area is home to about 200,000 residents, quite similar to the I-270 corridor.

Significant suburban commuter ridership. Many local riders use the Tama monorail to connect to larger Japan Railway (JR) stations to access central Tokyo neighborhoods.

Differences to I-270

Transit-oriented development patterns. Japan has a meticulous national rail system, and local cities and regions have their own even more robust transit systems. Citizens do not need to be convinced to change their travel mode to train/monorail, which they would for an I-270 monorail.

Design & Operation

Speed: 40 MPH (average)

Travel Time: Local: 24 min., Rapid: 21 min.,

Airport Express: 13, 16, and 18 minutes (depending on the terminal)

Headway: 5 minutes

Cost: Construction cost: $2.4 billion USD

Operating Expenses: approximately $645,000 USD

Number/Type of Vehicles: Hitachi 1000 series (1500V DC)

Infrastructure: Straddle-beam

Technology: Alweg, driver, electric

Fare Structure: Distance-based $1-3.75 USD (.05 miles-10 miles)

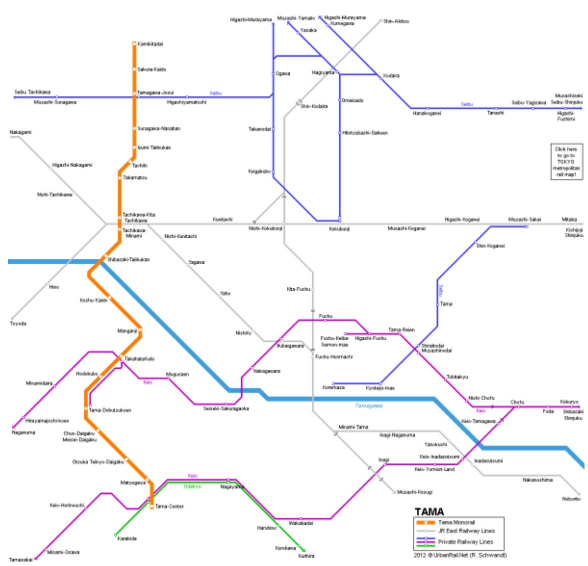


Figure 11: Tama Monorail map. The Tama Monorail (orange) connects to many other railway lines around Tokyo. Source: UrbanRail.net

WUPPERTAL, GERMANY

Description

The 8.26-mile suspended monorail was opened in 1901. The monorail still operates today traversing both urban and suburban areas running along the Wupper River serving 20 stations between the Elberfeld and Barmen city centers.

Year Open: 1901

Length: 8.26 miles

Number of Stations: 20

Ridership (2008): Daily: 65,000 – 80,000 Annual: 25 million

Similarities to I-270
Similar goal. The monorail, when built, was intended to solve the issue of increasing vehicle miles traveled.

Differences to I-270
Land-use patterns. The neighborhoods surrounding the Schwebebahn's stations are much denser than the I-270 corridor. Many stations are within walking distance to other transit stops (e.g., bus, regional trains). **Significant topographical barriers.** Topography not suited for traditional heavy rail system. Geological conditions (rocky and covered by water) prohibited construction of an underground metro. The footprint is quite minimal and takes advantage of the space above a river without requiring much land acquisition from the city.

Design & Operation

Speed: 17.1 MPH (average)

Travel Time: 30 minutes full trip

Headway: 4-6 minutes

Cost: The system has undergone multiple reconstruction efforts that have cost approximately $450 million USD.

Number/Type of Vehicles: 24 Articulated suspension railway trains GTW 72. 31 Articulated suspension railway trains G15 (2015)

Infrastructure: Suspension

Technology: Cars suspended from a single rail built underneath a supporting steel frame. The cars hang on rubber wheels and are powered by 750 V electric motors. The train's safety mechanism depends on the driver; driver must constantly push a pedal to control the train, otherwise train automatically stops (eliminated need of a second driver/assistant).

Fare Structure: Trip based: $3.18 USD (One ticket, any distance)

Figure 12: Map of Wuppertal Suspension Monorail
Source: Urbanrail.net

SUMMARY OF FINDINGS

The fast paced growth of numerous cities around the world has necessitated transit investments to help deal with the traffic induced from growth. Many cities are considering monorails as a viable alternative given their potentially lower construction cost, shorter construction times, and overall design flexibility. South American and Asian cities are at the forefront of this movement, having built the most monorail miles in the last decade, with plans for further expansion. The integration of monorails as an ancillary aspect of a larger transit network has been the key to the expansion of monorails, enabling suburban commuters traveling long distances to take transit into the downtowns of heavily urbanized areas and big cities.

As with other transit technologies not all monorail systems have been completely successful. A generally negative correlation has been observed from monorail systems that serve sparsely populated areas and/or do not integrate with other transit networks or monorail systems. A more positive correlation has been observed between monorail systems that serve more urban areas with large populations (over 500 thousand residents) that connect to a larger transit network. Most successful systems globally support local populations whom walk to monorail stations—this would be the exact opposite of the riders in Maryland whom would have to drive to a Park & Ride station (e.g., in Frederick) or take another transit service (e.g., local bus) to board the monorail.

Mass transit ridership mentality plays a crucial role in supporting ridership, with high ridership observed in regions that actively discourage single occupancy vehicle travel. Monorails are viewed as modern and integral parts of the transit network in Asia, Brazil, and Germany.

This global scan and assessment of monorail systems in service around the world, including those that are under construction, combined with the current monorail system supplier marketplace, illustrates that the technology continues to provide viable solutions for cities. The current offering of monorails is competitive among suppliers, based on in-service designs, with technological improvements akin to improvements made with all other transit solutions. The monorail as a transit alternative has endured for decades, and only within the last few has a resurgence in interest and supplier offerings spurred monorail construction.

In summary:

- Monorails have a demonstrable track record of providing viable urban transit.
- Monorails can provide unique solutions to address difficult alignments.
- Monorails compete with all other forms of transit for passenger capacity.
- Monorail technology is being constructed by multi-national transit corporations.
- The success of a transit system depends more on sound planning than it does on the specific technology.
- The monorail technology is as capable in providing multimodal connectivity solutions as is any other transit alternative.
- Successful monorail systems have the flollowing characterisitics:
    - serve a large population,
    - traverse a dense urban enviornment,
    - have transit-oriented development patterns,
    - have frequent headways,
    - have a reasonable fare structure, and
    - be easily accessible by car and on foot.
- The I-270 corridor, from I-370 to Frederick, does not fully demonstate all of these characteristics.

LESSONS LEARNED

This global scan and assessment highlights various case studies throughout the world. Each monorail that has been built comes with some lessons learned. The lessons learned from the aforementioned case studies are summarized below. Also included is an assessment of how these lessons relate to the I-270 corridor.

Lessons Learned from the Case Studies

Chongqing, China

- Monorail is a good alternative where urban development constraints exist.
- Monorail systems can work around geographic and urban development constraints.
- Monorail regional population center connectivity enables higher ridership.
- Low cost of riding Chongqing monorail encourages travelers to choose monorail.
- Monorail systems can be built to expand—both lines have had a series of extensions.

Daegu, South Korea

- Much like Chongqing, in Daegu the monorail had to work around geographic constraints.
- Monorail designs can be flexible and adaptable to fit the surrounding environment. Monorails are able to handle steep gradients, tight curves, and operate underground (with appropriate clearance for monorail track beneath train) in tunnels.

Las Vegas, United States

- Operating hours need to conform to the needs of the people using the system. In the instance of the Las Vegas monorail, it was necessary to understand the ridership of both tourists/visitors and local residents/employees in order to be successful. The monorail operating schedule needs to vary throughout the week in order to accommodate the users in this highly visited area.

Mumbai, India

- It is important to consult with the public and consider user demand for a monorail system before implementing plans to build.
    - The route planning and phase prioritization for the monorail was suboptimal, as they started the construction of project through mostly vacant areas, with limited shops, offices or residential blocks where there was minimal ridership.
    - Maintenance budgets and rigorous plans must be maintained from project evolution to deployment. Mumbai's monorail had a series of system/operational failures due to improper maintenance and operation—at one-point closing for ten months in 2017-2018.
- Monorail systems tend not to succeed unless they support or are supported by multimodal transportation. There was virtually no integration with other modes of transport, contributing to low ridership. The closest suburban railway station where the monorail ends is 2.5 miles away.

Osaka, Japan

- Monorails localized transit trips between contiguous stations can increase ridership and improve public perception of mass transportation.

- The monorail connects three different campuses of a university, providing localized transit options as well as longer-distance transportation to further stations.
- The connectivity to Itami Airport, the largest airport servicing Osaka, was an important expansion of the monorail. The line allowed access to the Osaka Itami Airport originating from two other transit lines thus increasing ridership.

Sao Paulo, Brazil

- Connection to existing transit is imperative.
    - Sao Paulo hosts the largest metropolitan rail transport network in Latin America—six lines operating along 60.4 miles of route, serving 86 stations, and carrying around five million passengers a day. Connection to this system increases the probability of high ridership.

Tokyo, Japan

- Estimate ridership revenues based on conservative ridership estimates.
- Expected ridership was overestimated, as there was less demand after the economic downturn. The Tama City Monorail was founded in 1986 but took 14 years to fully open due to financial obstacles. The company miscalculated the economic collapse and construction costs nearly doubled from the initial estimate. Much of the borrowed funds for the project were high-interest loans, which also led to the increased cost.

Wuppertal, Germany

- High frequency of trains supports higher ridership. Trains arrive every 4 - 6 minutes to support the 65,000 daily riders (Tautonline). A higher frequency of trains makes it more appealing to riders to use the system.
- Connecting urban centers allows for growth. The areas along the Schwebebahn urbanized as a result of the easy connectivity to both Barmen and Elberfeld.

Relating to I-270

- The integration into the transit network is key in making monorails attractive and easy to use for riders. Seemless connection to other forms of transit such as heavy rail can lure suburban commuters traveling long distances to take transit into the core of heavily urbanized areas. International examples of these are Sao Paulo and Chongqing monorails.

    - The I-270 corridor connects to a large transit network that includes the WMATA Metro Rail, Metro Bus, Amtrak, MARC train, and other local buses. Many commuters and tourists coming from the north (Frederick area) will go further south past the Shady Grove Metro requiring a transfer to another form of transit to reach their destination. The amount of transfers required to reach a destination will have an impact on how many people are willing to use it. The cities of Sao Paulo and Chongqing are very large and densly populated, much more so than the communities that the I-270 corridor serves. Any additional transit options for the I-270 corridor will need to be easily accessible with easy access from other transit and sufficient parking at those stations located outside of developed areas. A user of the system must be able to actually use the system and the ease of access and the connectivity between the transit network modes is key.

- Monorail systems work best in areas of higher population density with concentrated urban development next to stations.
    - The I-270 corridor is far more suburban in nature and is not comparable to other corridors in cities with some of the most successful monorails like Chongqing and Sao Paulo.
    - Mumbia has not had the expected success with their monorail in part because the monorail fails to connect to populated areas and instead has stops in more vacant areas with minimal development compared to the rest of the populated region the monorail could be serving.
- Related to the previous, building a monorail as part of a Transit Oriented Development (TOD) strategy can work, but needs careful planning and time. The addition of a monorail can spur residential and commercial development at its stations and can serve as an opportunity for smart growth. However, the pace of the development may be slower without existing demand, for instance in dispersed suburban areas. Monorails in Mumbai and Tokyo are good examples of this.
    - Communities along the I-270 corridor may have town centers with areas of more concentrated development, but are generally dispersed. The stops at many stations will not be walkable. While Park and Ride and mobility hub designs for surrounding stops will need to be a part of the monorail stations, it is important that a clear TOD strategy is developed to ensure a sustainable, smart, and walkable urban environment around each stop so that people are able to access the stations.
- Monorails can have low impact, flexible designs. A common characteristic of monorails is their ability to occupy limited right of way, easily accomodating curves and grade changes. Chongqing and Daegu monorails are good examples of monorails that traverse through difficult urban and rural topographies.
    - I-270 has limited right of way throughout a generally flat and straight, vertical and horizontal profile, respectively. However, it does pass through some environmental features, such as parks, rivers, and creeks.
- The I-270 monorail will require a behavioral shift from single-occupancy vehicle travelers to mass transit commuters, which may hinder estimated ridership. Most successful monorails were deployed in areas where established mass transit was already the main mode of transportation and per capita auto ownership is lower than in the USA. Additionally, Transportation Demand Management (TDM) strategies could also help in creating this shift.

It is notable that from the above lessons learned, the system specific characteristics that are highlighted for a successful monorail, equally apply to Light Rail, Bus Rapid Transit, or even Rail Rapid Transit (Metro). You could replace the word monorail with any of the alternative transit types, and the lesson would be true. The implication is that the success of a transit system rests more on successful planning, than it does with the transit type.

Finally, MDOT is developing a comprehensive traffic study of the I-270 corridor's monorail viability. That study will include a more sophisticated traffic engineering review which will clarify technical questions that were not covered in this assessment. Key details such as ridership demand, environmental impact, and potential cost are examples of technical elements that are crucial to learn as part of the overall project analysis.

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APPENDICES

Appendix A – Global Scan Summary

Appendix B – Monorail Marketing Material, Recent Examples

Appendix C – Farebox Recovery and Operating Expense Data Overview