APPENDIX C

MDOT Monorail Global Scan and Assessment, November 2020

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.

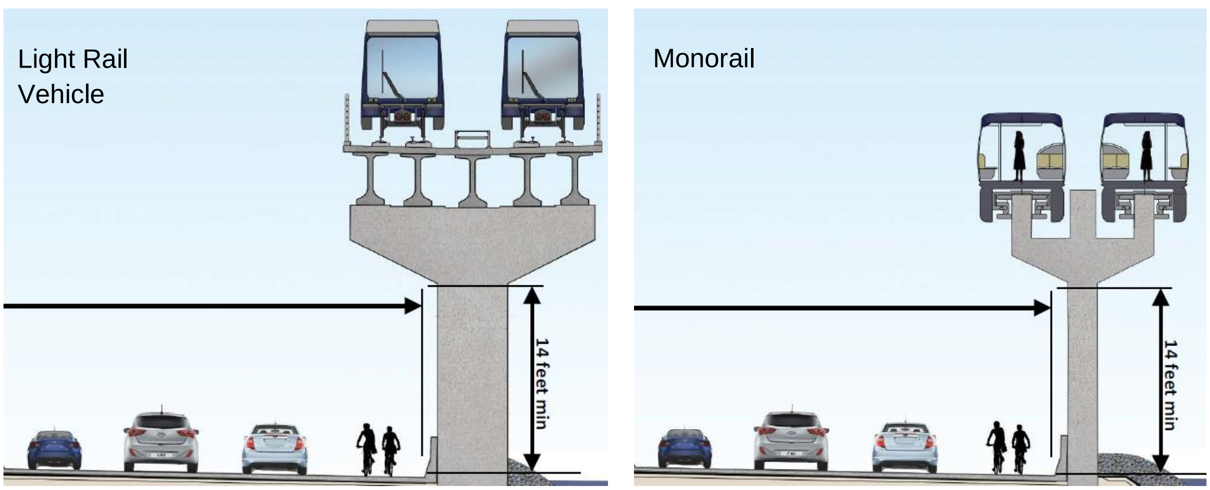


Figure 2: Monorail guideway comparison

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

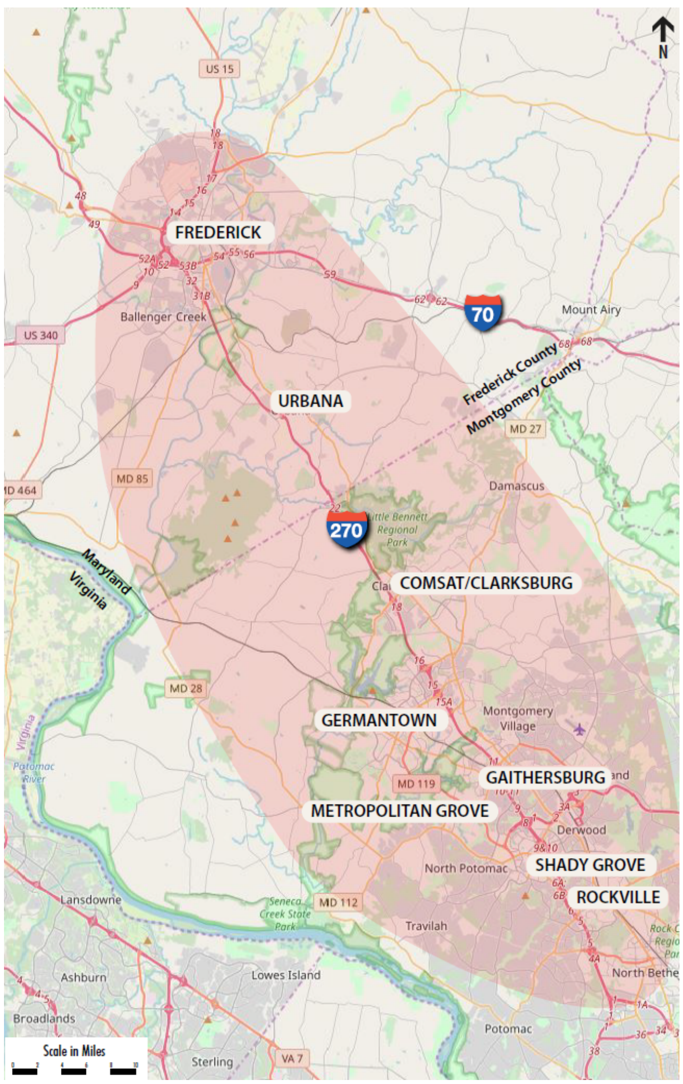
Cities under Contract	Year in Contract
Panama City, Panama	2018

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)

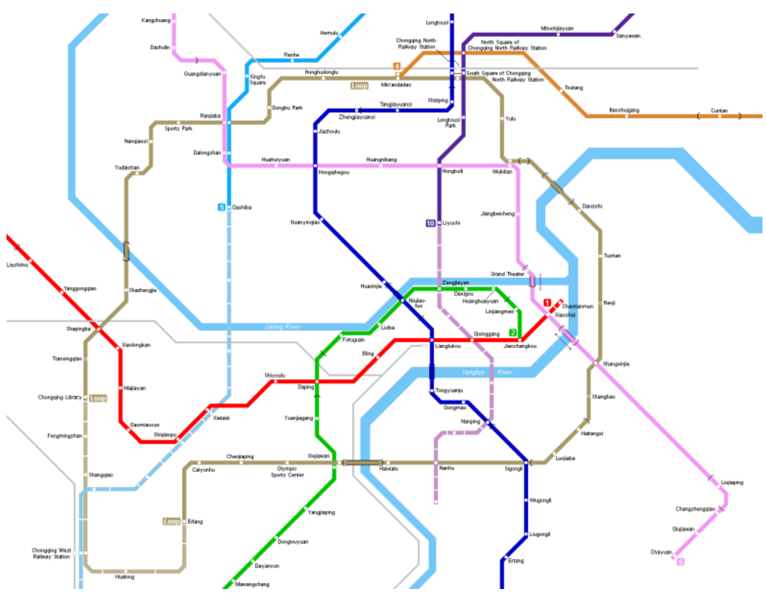


Figure 5: Chongqing Rail Transit Map. Line 2 (Green) and Line 3 (Dark Blue) Source: Urbanrail.net

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)

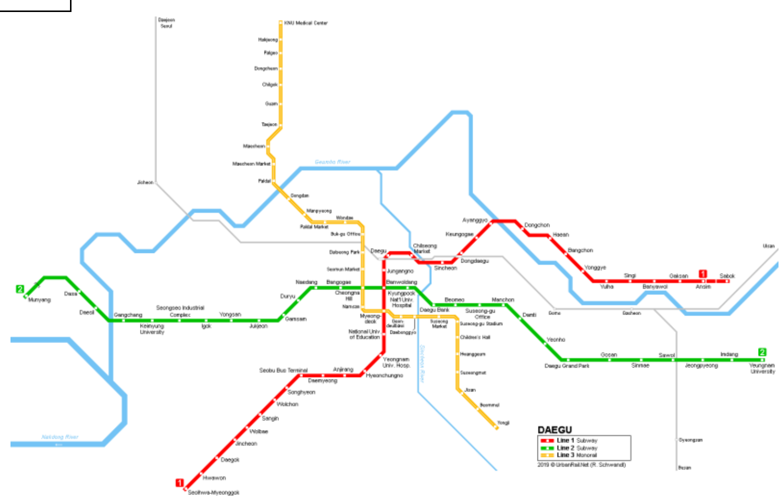


Figure 6 Map of Daegu Metro System Line 3 (Yellow) monorail. Source: Urbanrail.net

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)

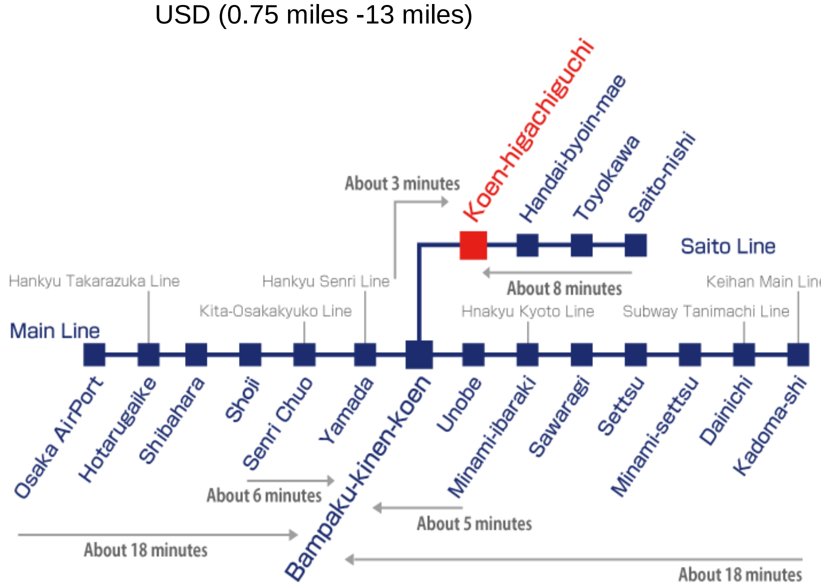


Figure 9: Osaka monorail. Source: minpaku.ac.jp

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)

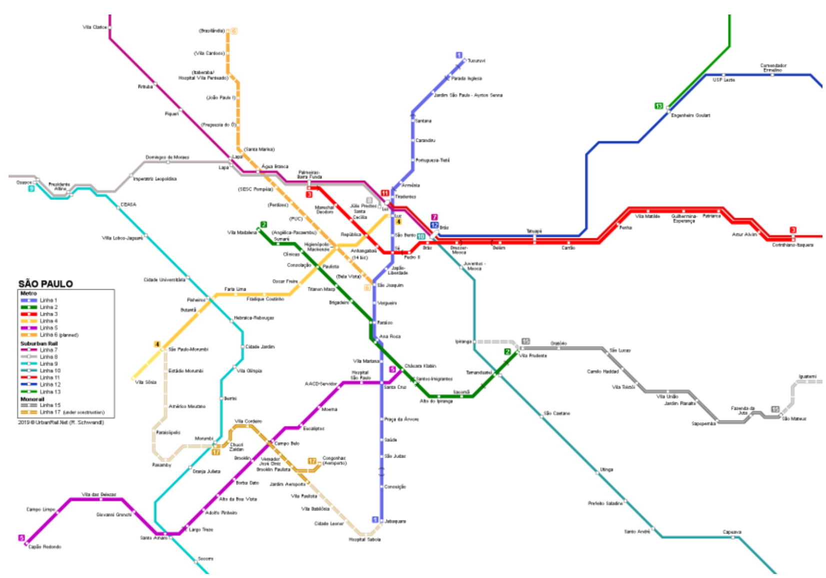


Figure 10: Map of Sao Paolo Metro System. Line 15 (Silver), an extension of Line 2 (Green), is the existing Monorail. Source: Urbanrail.net

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)

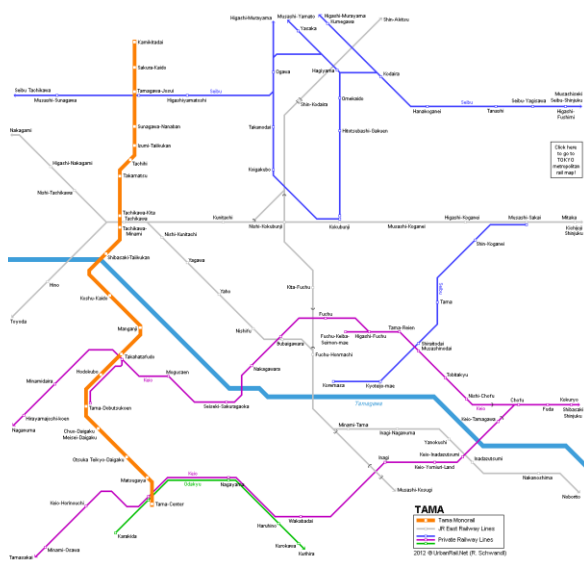


Figure 11: Tama Monorail map. The Tama Monorail (orange) connects to many other railway lines around Tokyo. Source: UrbanRail.net

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

Location	Year Open	Length	# Stations	Ridership (Daily Average)	Ridership (Annual)	Speed	Travel Time	Design/Construction Cost	Number and Type of Vehicles	Infrastructure	Technology/Guidence System
Australia, Broadbeach	1989 (Closed 2017)									Straddle-beam	Steel box beam
Australia, Queensland, Sea World	1986	1.2 miles	2			17 mph		$3M (Australian)	3, 9-car trains	Straddle-beam	Von Roll Mk II
Australia, Sydney	1988 (Closed 2013)	2.24 miles	8		70 million (lifetime)	21 mph (average)	12 minutes (entire loop)	$55 million USD (construction) $10-15 million USD (demolish)	Von Roll Type III, 6, 7-car trains	Straddle-beam	500 V AV power, generator provided to clear trains in emergencies. Built to operate autonomously, breakdowns soon after opening led to decision to retain drivers for each train
Belgium, Lichtaart	1975	1.15 miles	3			4.7 mph	15 minutes	Approx. $550,000 dollars (1978)		Straddle-beam	Schwarzkopf
Brazil, Salvador	2021 (proposed estimate)	12.4 miles	22	Capacity of 150,000 passengers a day				$650 million (approximately)		Straddle-beam	BYD Skyrail
Brazil, Sao Paulo, Line 15 (Expresso Tiradentes)	Phase 1: 2016 Phase 2: 2018	4.7 miles (out of 17 miles planned)	6 (out of 18 planned)	500,000 (estimated once fully completed) 40,000 passengers per hour per direction		50 mph (average)	12 min (50 minutes end to end once fully completed)	$1.6 billion (estimated for entire project, not clear what is included in this amount)	54 seven-car trains (total once completed), Bombardier Innova 300	Straddle-beam	CITYFLO 650 automatic train control
Brazil, Sao Paulo, Line 17 (gold)	2022 (estimate)	11 miles	(8- to be expanded to 10)	85,000/day (expected)						Straddle-beam	ALWEG
Brazil, Sao Paulo, Line 2 (green) Extension	(construction to start on 2020)	5.16 miles		377,000 riders per day (expected)				$1.4 billion (estimated for entire project, not clear what is included in this amount)	22 trains		
Brazil, Sao Paulo, Line 18 (bronze)	2018	9.6 miles	13							Straddle-beam	ALWEG
Canada, Montreal, La Ronde	1967	1 mile	2			6.2 mph (max)				Straddle-beam	Von Roll
Canada, Montreal	In planning	7.33 miles	7					$1.1 billion (estimated)			
China, Beijing	Planned		21					$3.27 billion		Straddle-beam	
China, Bengbu	In planning										
China, BYD Garden Line, Shenzhen	1998		4						5 P28/24 class trains (500mm wide and 700mm high box beam guideway)	Straddle-beam	
China, Dapeng	Under construction	37.3 miles									
China, Fenghua	In planning										
China, Guang'an	2019	6.1 miles	7							Straddle-beam	BYD Skyrail

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China, Happy Line Monorail, Shenzhen, China	1998	1.5 miles	7						"fleet of five P28/24 class, three-car trains, each with a capacity of 24 passengers". Monorail beam has dimensions of 500mm wide and 700mm tall with a support column every 15 meters	Straddle-beam	
China, Shanghai, Red Star Macalline	2008	0.37 miles								Straddle-beam	
China, Shanghai										Straddle-beam	Maglev (Magnetic Levitation)
China, Shantou	2020 (expected)	12.2 mi (55 km line under construction, 250 km planned)	18			50 mph				Straddle-beam	BYD SkyRail
China, Shenzhen, Happy Line	1998	2.4 miles	7						5 (24 passengers/train)	Straddle-beam	Intamin, P28/24, three-car trains
China, Shenzen, Window of the World	1993	1 mile	3							Straddle-beam	
China, Shenzen, BYD Garden Line		3.1 miles	7			50 mph (maximum)				Straddle-beam	BYD SkyRail
China, Xi'an	2015	5.97 miles	11						Intamin, P8/48, 3 vehicles (48 passengers)	Straddle-beam	Steel box beam
China, Yinchuan, Yungui monorail	2017	3.52 miles/5.67 km (expected to build city network to 300 km over next few years)	8			50 mph (maximum)		$760 million		Straddle-beam	BYD SkyRail
China, Pingshan Demonstration Line, Shenzhen,	In planning	3.36 miles									
China, Chongqing	Line 2: 2005 Line 3: 2011	Line 2: 19.4 miles Line 3: 41 miles	Line 2: 25 Line 3: 45	Line 2: 234,200 (2014) Line 3: 682,800 (2014)		50 mph (maximum)		Line 3: USD $2.1 billion	76 total cars arranged into four-car trains with a double axle bogie track	Straddle-beam	Hitachi, DC: 1,500 V electrical system, VVVF traction inverter control unit, and ATP two-man operated operating system.
China, Giulin	Under construction	17.4 miles	6			50 mph					
China, Huashan	In planning										
China, Wuhu, Anhui	2020 (expected)	28.71 miles	35 (expected)						Bombardier Innovia	Straddle-beam	
China, Jilin Line 1, Jilin, China	In planning	105 miles				49.71 mph				Straddle-beam	
China, Jining	Testing	21.75 miles				49.71 mph					BYD Skyrail
China, Zhongshan	In planning									Straddle-beam	BYD SkyRail

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Egypt, Cairo, East Cairo to New Administrative Capital	Under construction	33.6 miles		45,000 passenger per hour per direction (estimated)			60 minutes (estimated)	$4.5bn including O&M for 30 yrs for both lines in Cairo (so including 6th October to Giza)	70 four-car Innovia Monorail 300 trains for both line in Cairo	Straddle-beam	Cityflo 650 signaling and automatic train control
Egypt, Cairo, 6th October to Giza	Under construction	26.1 miles		45,000 passenger per hour per direction (estimated)			42 minutes (estimated)	$4.5bn including O&M for 30 yrs for both lines in Cairo (so including East Cairo to New Administrative Capital)	70 four-car Innovia Monorail 300 trains for both line in Cairo	Straddle-beam	Cityflo 650 signaling and automatic train control
Finland, Helsinki, Linnanmaki Maisemajuna	1979	0.31 miles	1							Straddle-beam	Gebr. Ihle, Bruchsal
Germany, Dortmund, H-BAHN	1984	2 miles	5		Up to 8,000 a day and "capable of moving 2,000 passengers in one direction per hour"	31 mph	Different connections, not a single line		Aluminum driverless cars	Automatically controlled suspended monorail	Aluminum driverless cars suspended from a hollow beam with dual axle with sliding doors at glass walled stations, running gear fitted with hard rubber types (to make it quieter), slide mounted wheels (inside the beam), two independent traction systems and combined regenerative-rheostatic braking system
Germany, Düsseldorf	2002	1.6 miles	4			32 mph	14.5 minutes total			Automatically controlled suspended monorail and gondola lift	Fully automatic gondola lift
Germany, Europa Park (Theme Park in Rust Germany)	1995						13 minutes		93 seats and maximum capacity of 1200 people per hour	Straddle-beam	Alweg (Von Roll Type II)
Germany, Wuppertal	1901	8.26 miles	20	65,500-80,000	25 million (2008)	17.1 mph (average)	30 minutes (entire length)	$450 million reconstruction since (2004)	Articulated suspension railway trains GTW 72 (24 cars) Articulated suspension railway trains G15 (31 cars) introduced 2015	Suspended	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).
India, Mumbai	Phase 1: 2014 Phase 2: 2019	Phase 1: 5.5 miles Phase 2: 6.6 miles	17	Phase 1: 17,000 (2019), Phase 2: < 5,000 (2019)		19 mph (avg), 50 mph (top speed)	3 minute headway	$501.9m	Phase 1: 15 trains Phase 2: 4 trains (expected 17 trains by 2021)	Straddle-beam	Alweg technology

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Iran, Qom	Under construction	4.35 miles	8	12,000 / pphpd (expected)				$120 million	20 driver-operated 4-car units (56 m long), to be increased to 36 in second stage	Straddle-beam	
Italy, Savio, Ravenna Mirabilandia	1999	1.24 miles	2							Straddle-beam	
Italy, Bologna / Marconi Express	2019 (expected)	3.11 miles	3		Estimated demand of around 1 million. Capacity of 560 passengers per hour per direction , corresponding to 5,183,000 p/year.	25 mph average	7 minutes 20 seconds (end-to-end)		3 vehicles, type P30/50 trains.	Straddle-beam	Automatic (no driver)
Italy, Venice	2010	.54 miles	3			18 mph	1.5 minutes		2 four car trains (50 passengers per vehicle and 200 passengers per train)	Straddle-beam	Elevated steel truss piers/columns
Japan, Chiba, Japan	1988, 1995	9.45 miles	19 (total between the two)	12,500	17.5 million	12.43-18.64 mph			2-car train Safeju type suspended monorail	Safeju type suspended monorail (two lines)	SAFEGE
Japan, Kitakyushu	1985	5.47 miles	13	30,177 (2013)		16.78-40.39 mph		$550 million (1985 dollar)	10 four car	Straddle-beam	ALWEG
Japan, Shonan	1970	4.1 miles	8	15,000	10 million	45 mph (top speed)	14 minutes (entire line)		Mitsubishi 5000 series 3-car sets	Suspension	SAFEGE
Japan, Tokyo, Tama Toshi Monorail	Phase 1: 1998 Phase 2: 2000	10 miles	19	44,000	50.5 million	40 mph (average)	Local: 24 min. Rapid: 21 min. Airport Express: 13, 16, and 18 minutes (depending on the terminal)	USD $2.422 billion	Hitachi 1000 series (1500V DC)	Straddle-beam	Alweg technology, driver, electric
Japan, Tokyo, Haneda Monorail	1964	11 miles	10	78,726	45 million	50 mph		USD $265.6 million (1964 dollar)		Straddle-beam	ALWEG
Japan, Osaka	1990	17.4 miles	18	27,391	44.5 million	45 mph (maximum)	35 minutes (entire route)		Hitachi four-car trains	Straddle-beam	Alweg-Hitachi technology, 1500 V electric
Japan, Higashiyama	Under construction	1.24 miles	2							Straddle-beam	
Japan, Okinawa, Naha / Yui Rail	2003	8 miles	15	49,716 (2017)	16 million	40 mph		$352 million (2003 dollar) Other source cites a cost of USD $1.1 billion, more in line with expectations	14,700 mm long, 2,980 mm wide, and 5,100 high.	Straddle-beam	Two-axis bogie electric control passenger car, two-car fixed organization (Mc1,Mc2)
Japan, Kanagawa	1970	4.1 miles	8			45 mph	14 minutes (comes every 7-8 minutes)		Seven three-car aluminum-bodied 5000 series train seats from Mitsubishi Heavy Industries	Suspended	SAFEGE

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Japan, Tokyo, Disneyland Urayasu	2001	3.11 miles	4	28,416	20.9 million	31.1 mph	13 min		five, 6-car trains (up to four trains operating on loop simultaneously)	Straddle-beam	ALWEG
Japan, Tokyo, Taito Ueno Zoo	1957	0.19 miles	3				90 seconds			Suspended	Single track
Malaysia, Kuala Lumpur	2003	5.3 miles	11	63,778 (2017)	23.279 million (2017)	37 mph	5 min headway	Construction: $209 million USD Upgrades: $125 million USD (12 new trains)		Straddle-beam	ALWEG
Malaysia, Malacca	2010 (2010-2013, and 2017-present)	1 mile					30 minutes	$4 Million		Straddle-beam	ALWEG
Mexico, Mexico City		1.9 miles				28 mph	4 minutes 40 seconds		4 carriages with 25 person capacity each and capable of up to 6,800 passengers daily	Straddle-beam	Automated electric train using 6-km cable system and with a tubular steel base carriage
Nigeria, Calabar	2016		3			25 mph average			12-car train powered by Intamin P8 electric (38.5 meters long, 1.95 meters wide, and 2.2 meters high)	Straddle-beam	
Nigeria, The Rivers Monorail, Port Harcourt, Nigeria										Straddle-beam	
Panama, Panama City	2022	16.6 miles	14				45 minutes	$2.6bn	28 six-car trains	Straddle-beam	
Philippines, Iloilo	2019 (expected)	12.4 miles								Straddle-beam	BYD SkyRail
Russia, Moscow	2004	2.9 miles	6			37 mph		$240 million		Straddle-beam	Steel box beam
Saudi Arabia, Riyadh	Under construction								Bombardier Innova 300	Straddle-beam	
Singapore, Sentosa, Sentosa Express	2007	1.3 miles	4				8 minutes			Straddle-beam	Hitachi
South Korea, Seoul, Lotte World	1986									Straddle-beam	Steel box beam
South Korea, Daegu	2015	14.9 miles	30	74,031 (2017)		20-45 mph (range of standard operating speeds)	50 minutes (full length)	$792 million	28 hitachi monorail sets with 84 cars. 15m long, 2.9 m wide, and 5.24 m high.	Straddle-beam	Digital ATP/ATO/ATS driverless system and two closed-circuit surveillance cameras.
Spain, Zaragoza	2008	0.31 miles	2				2.5 min		4-car trains, 36 passengers (2 wheelchairs)	Straddle-beam	Van Roll, manual or semi-automatic
Taiwan, E-DA Theme Park Dashu District (Kaohsiung City)										Straddle-beam	

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Thailand, Bangkok	2022	Yellow: 18.64 miles Pink: 21.13 miles	53 (30 pink and 23 yellow)			50 mph		USD $1.7 billion (yellow line) and USD $1.75 billion (pink line)		Straddle-beam	
Thailand, Chiang Mai	2008 (closed 2014)									Straddle-beam	
The Philippines, Balanga city	In planning	4.35 miles (planned)								Straddle-beam	BYD Skyrail
The Philippines, Iloilo city	In planning									Straddle-beam	
Turkey, Ankara	2012	.31 miles	3							Straddle-beam	
Turkmenistan, Ashgabat	2016	3 miles	8			28.6-43.5 mph			Up to 75 passengers	Straddle-beam	Steel box beam
UAE (United Arab Emirates), Dubai	2009	3.36 miles	4			22-43.5 mph				Straddle-beam	ALWEG
UK, Chester Zoo Monorail, Chester Zoo, England	1991	0.93								Straddle-beam	Steel box beam
UK, Alton, Alton Towers	1987	2 miles								Straddle-beam	ALWEG, Vol Roll Type II
UK, Beaulieu	1974	1 mile	2							Straddle-beam	Unknown
United States, Orlando, Disney World	1971	14.7 miles	6 (3 lines)	Over 150,000	50 million	40 mph			Mark VI trains with cars, up to 360 people per train	Straddle-beam	Alweg
United States, Anaheim, Disneyland	1959	2.5 miles	2			30 mph	13 minutes round trip		Red, Blue, and Orange Mark VII trains (5 cars with up to 145 passengers per train)	Straddle-beam	600-volt DC power source
United States, Hawaii, Pearlridge Mall	1967	0.31 miles	3						Four cars with up to 64 people at a time.	Straddle-beam	Rohr Industries
United States, Jacksonville	1989	2.5 miles	8	5,000 per day (2015)	840,000 annually (2018)	35 mph	Train arrives every 4 minutes during peak hours and every 8 minutes during off-peak hours	$182 million	Six two-car trains	Straddle-beam	UM III monorail technology, fixed 11-foot guideway with parapet walls, and automatic train control (ATC). The train model is not in production anymore and parts are also difficult to get.
United States, Seattle	1962	1 mi	2	unknown (more varied than other transit modes in Seattle e.g. light rail, buses)	2.15 million (2014)	45 mph	service every 10 minutes (5 minutes during special events and activities with two trains running) and each trip takes two minutes.	$3.5 million (construction),	Two trains (circa 1962)	Straddle-beam	68 y-shaped columns supporting pairs of 70 foot long and 30 foot high concrete beams and 64 tires on each train (48 guide tires and 16 load tires).

Appendix A
Global Scan Summary

Location	Year Open	Length	# Stations	Ridership (Daily Average)	Ridership (Annual)	Speed	Travel Time	Design/Construction Cost	Number and Type of Vehicles	Infrastructure	Technology/Guidence System
United States, Tampa, Florida	2018	1.4 miles	3				Less than five minutes and trains come about every two minutes		12 cars and up to 3,990 people per hour	Straddle-beam	TGI/Bombardia
United States, Las Vegas	2004 (1995)	3.9 miles	7 (8th planned)	13,500/average daily	2.9 million (2016)	50 mph (maximum)	15 minutes (end to end) and 4-8-minute headways	$350 million-construction	Bombardier M-VI monorail fleet with nine four-car trains (36 cars).	Straddle-beam	Bombardier trains
United States, Newark	1996	Phase 1: 1.86 miles Phase 2: 1.12 miles	8 station (including the connection to NJ Transit)	Around 30,000 passengers a day between terminals A, B and C, the airport's parking and rental car lots, and a station linking the airport to NJ Transit trains along the Northeast Corridor line.	11 million	Maximum speed of 27 mph during peak periods	Travel times from Newark Liberty International Airport Station to passenger terminals vary. Terminal C - 7 min. Terminal B - 9 min. Terminal A - 11 min.	Phase 1: USD $354 millions Phase 2: USD $415 millions	18 six-car trains	Straddle-beam	ALWEG
Vietnam, Da Nang, Asia Park	2016	1.12 miles	3					$177.8 million	Up to 2,000 passengers an hour	Straddle-beam	Intamin P6 trains

APPENDIX B
MONORAIL MARKETING MATERIAL, RECENT EXAMPLES

B.1 Bombardier

B.2 BYD

B.3 CRRC

B.4 Hitachi

APPENDIX – B.1 BOMBARDIER MONORAIL MARKETING

INNOVIA Monorail 300 system

Transportation Systems

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TOP SUPPLIER AROUND THE WORLD

Driverless monorail systems

Bombardier is a world leader in the monorail systems segment:

- **Over two decades of experience**
- **Flagship performance in urban transportation**
- **Over 600 vehicles ordered or in operation in six cities and airports**
- **Industry-leading system availability levels as high as 99.02%**

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THE EVOLUTION OF THE MONORAIL TECHNOLOGY

Technology background

Monorails originated in early 1900s with two different technologies:

Suspended technologies

Schwebebahn Wuppertal, Germany, in operation since 1901

Straddle beam

1950s ALWEG monorail test track in Germany

1st ALWEG monorail in commercial operation, Disneyland 1959

- **ALWEG design attracted attention of Disney**
  - Installed globally in Disney parks
  - Popularised as theme park application
- **ALWEG design is basis for:**
  - Disney, Bombardier Las Vegas, Hitachi

Today, over 50 monorail systems are in operation around the world[1]

[1] The Monorail Society www.monorail.org

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YESTERDAY'S PERSPECTIVE OF RAIL SYSTEMS

Technology background

Mass transit systems:

- Underground
- Congested and heavy
- Metro system only option for high capacity service

Monorail systems:

- Elevated
- Futuristic and impractical
- Only suitable for low capacity service; such as amusement parks

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GAME CHANGING URBAN TRANSPORTATION SOLUTION
INNOVIA Monorail 300 system

The *INNOVIA* Monorail 300 system incorporates the design and operational features required for rigorous urban line-haul service

- Fully automated and driverless mass transit solution
- Futuristic appearance and aerodynamic design
- Speeds up to 80 km/h
- Minimised headways for highest frequency of service
- Energy efficient technologies
- High passenger capacity
- Superb comfort and ride quality

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SUITABLE FOR A RANGE OF APPLICATIONS

Tomorrow's technology today

The *INNOVIA* Monorail 300 technology combines the high capacity of mass transit systems with monorail's sleek look and elevated operation

- **Collector distributor**
  - 2,000 to 10,000 pphpd
  - feeder system to mass transit network
  - seamless integration into urban environment (including through buildings and structures)

- **Line haul (medium to high capacity)**
  - 5,000 to 48,000 pphpd
  - frequent and reliable passenger service
  - dedicated right-of-way provides unrestricted operation

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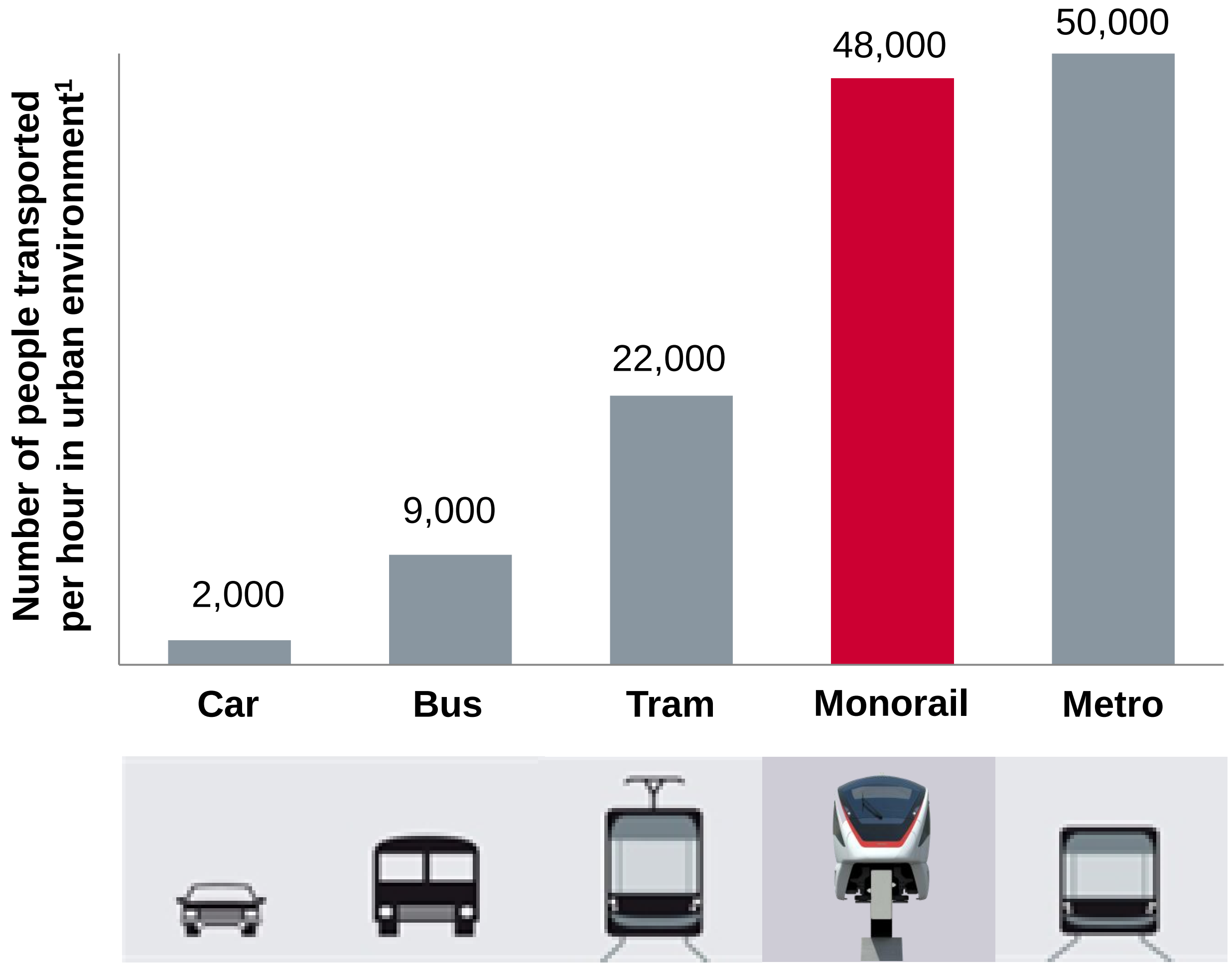
A COMPETITIVE SOLUTION

Mass transit capacity



[1] International Association of Public Transport (UITP); Institute for Sustainability and Technology Policy, Murdoch University. Number of people crossing a 3 to 5 metre-wide space in an hour in an urban environment (Monorail added by BT)

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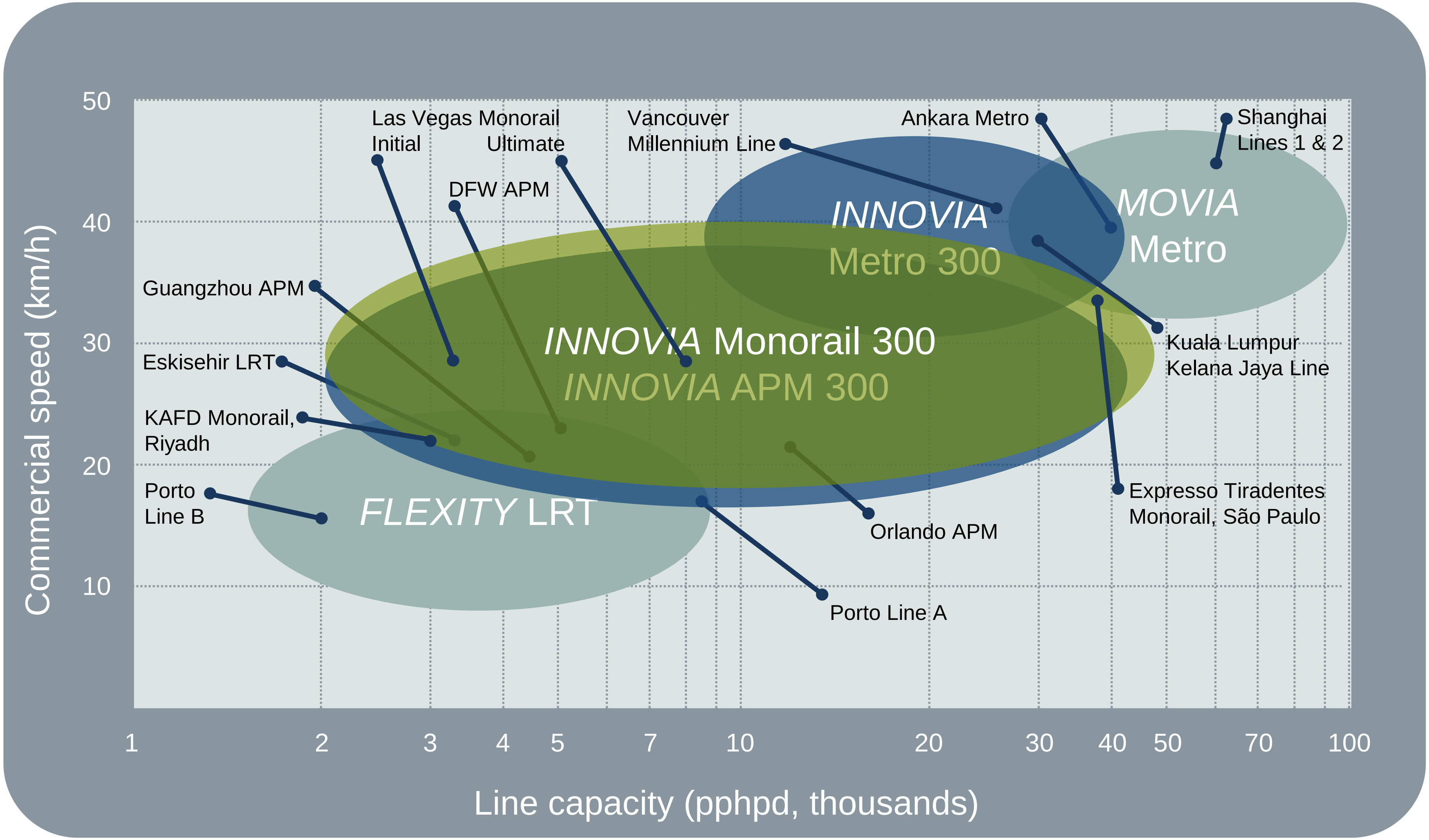
HIGHLY FLEXIBLE CONFIGURATIONS AND CAPACITIES

Top performers



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CAPACITY COMPARISON

INNOVIA Monorail 300 vs. other transit solutions

TECHNOLOGY	DESCRIPTION	NUMBER OF CARS	Capacity at 6 passenger / m² VEHICLE CAPACITY	120 SECOND HEADWAY	90 SECOND HEADWAY
Heavy metro	Smaller size (Rc+M+M x 2)	6	1,016	30,500	40,600
	Medium size (Rc+M+M x 2)	6	1,508	45,200	60,300
	Large size (Rc+M+M x 2)	6	1,736	52,100	69,400
Monorail	7-car train	7	1,002	30,080	40,000
Tramway	30 metre	1	270	8,100	10,800
	2 coupled 30 metres	2			21,600
	40 metre	1	380	11,400	15,200
	2 coupled 40 metres	2			30,400
Standard bus	With 2 axles	1	85	2,550	3,400
	Articulated	1	121	3,650	4,840
	Bi-articulated	1	173	5,200	6,920
Bus in segregated line	Type milenio Bogota	1	160	22,400	30,000

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SEAMLESS INTEGRATION AND ROUTE FLEXIBILITY

Urban fit

- Slender guideways are easily integrated into different environments
- Low profile sleek vehicles
- Infrastructure requires minimal land expropriation
- Flexible route alignment
- Sharp curve radii and steep grades
- Designed for seamless integration with buildings and structures
- Unobtrusive stations
- Quiet vehicle operation

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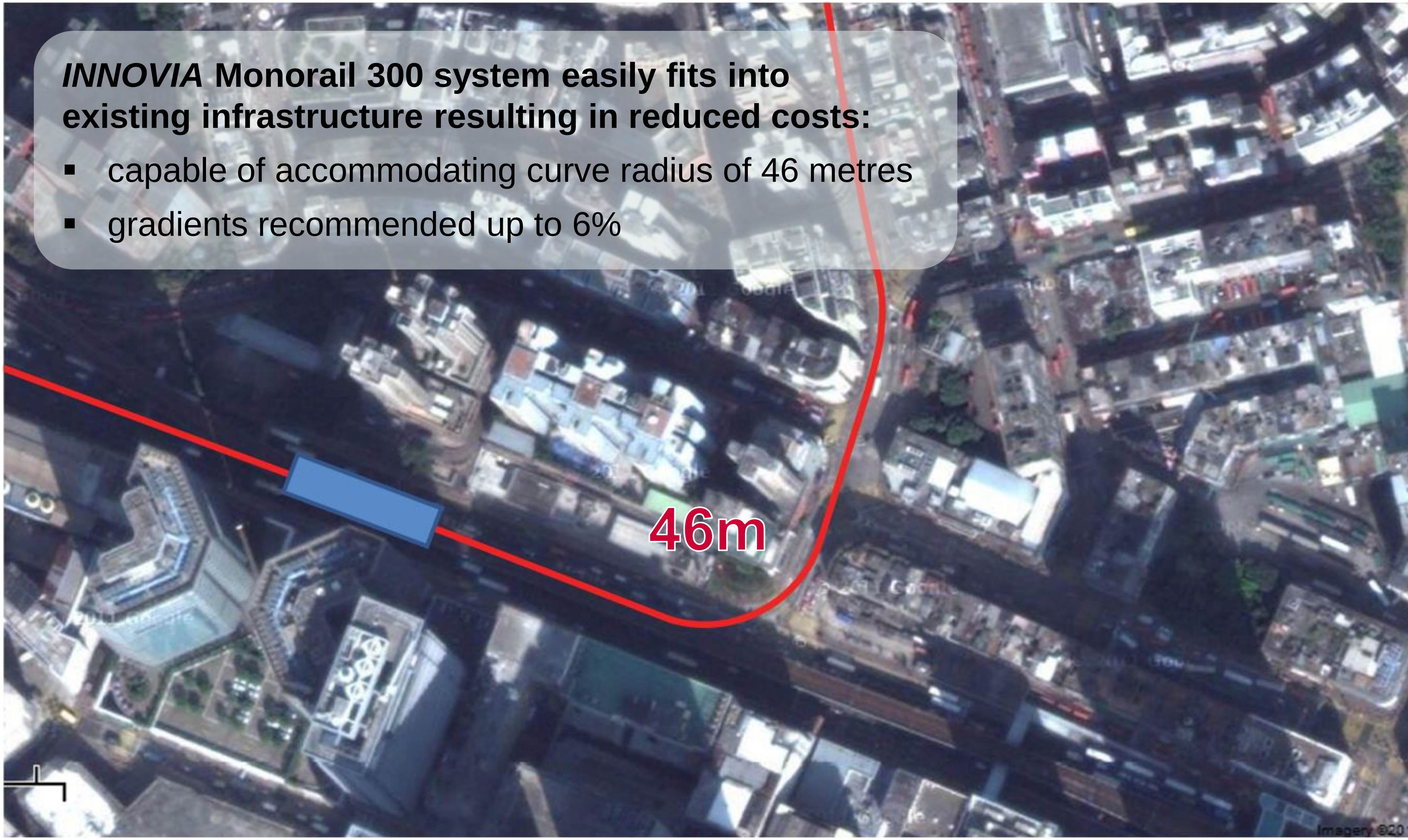
ALIGNMENT CAPABILITIES

Urban fit

***INNOVIA* Monorail 300 system easily fits into existing infrastructure resulting in reduced costs:**

- capable of accommodating curve radius of 46 metres
- gradients recommended up to 6%



Satellite picture © Google 2012
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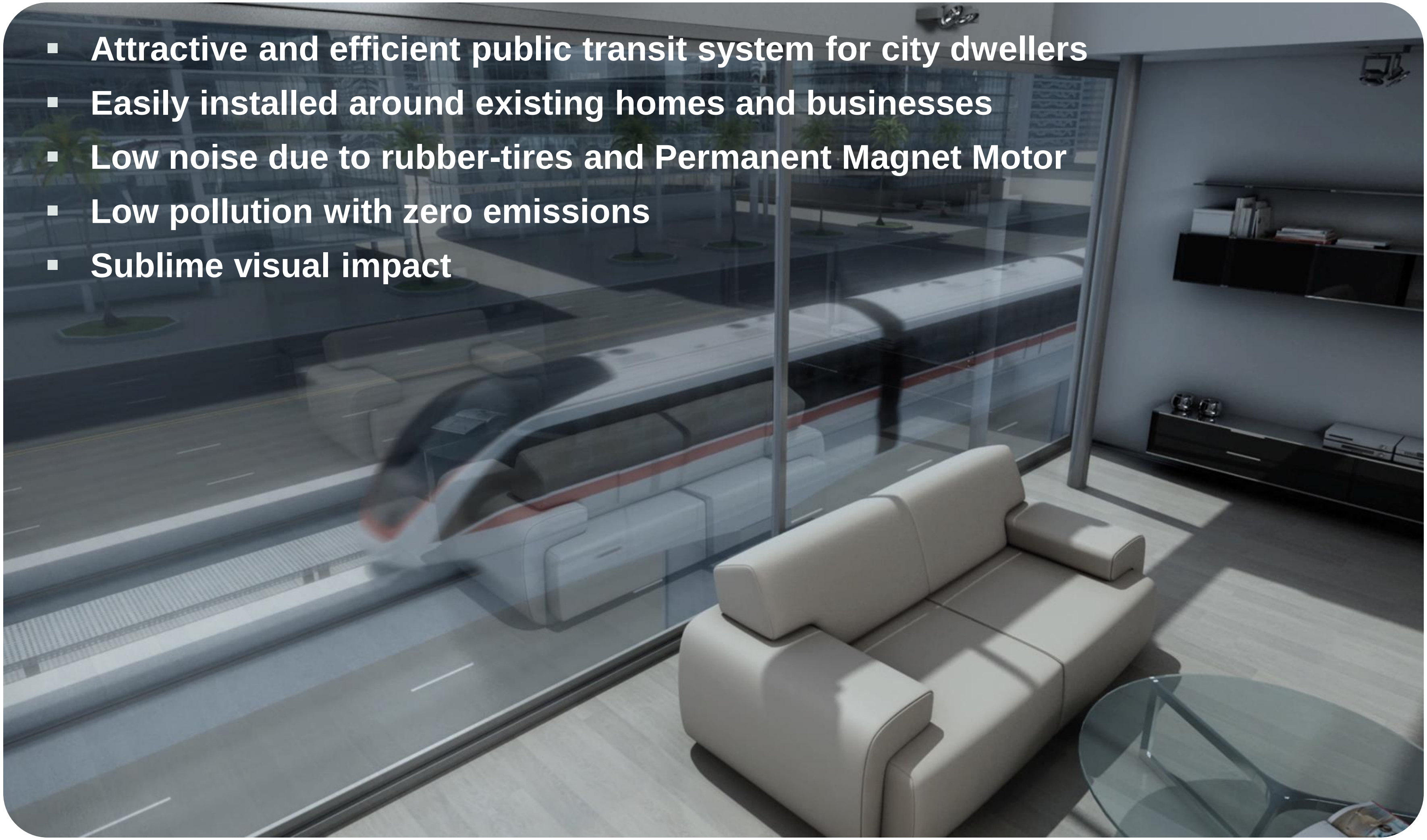
GOOD NEIGHBOUR

Urban fit



- **Attractive and efficient public transit system for city dwellers**
- **Easily installed around existing homes and businesses**
- **Low noise due to rubber-tires and Permanent Magnet Motor**
- **Low pollution with zero emissions**
- **Sublime visual impact**

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TURNKEY APPROACH

Integrated mobility solution

INNOVIA Monorail 300 systems were developed as turnkey systems for:

- integrated system operation
- minimised civil cost impact
- optimised for total lifecycle cost

Key advantages of a turnkey approach:

- one fixed price
- one party responsible
- one source for skilled people
- shorter, more reliable delivery schedule

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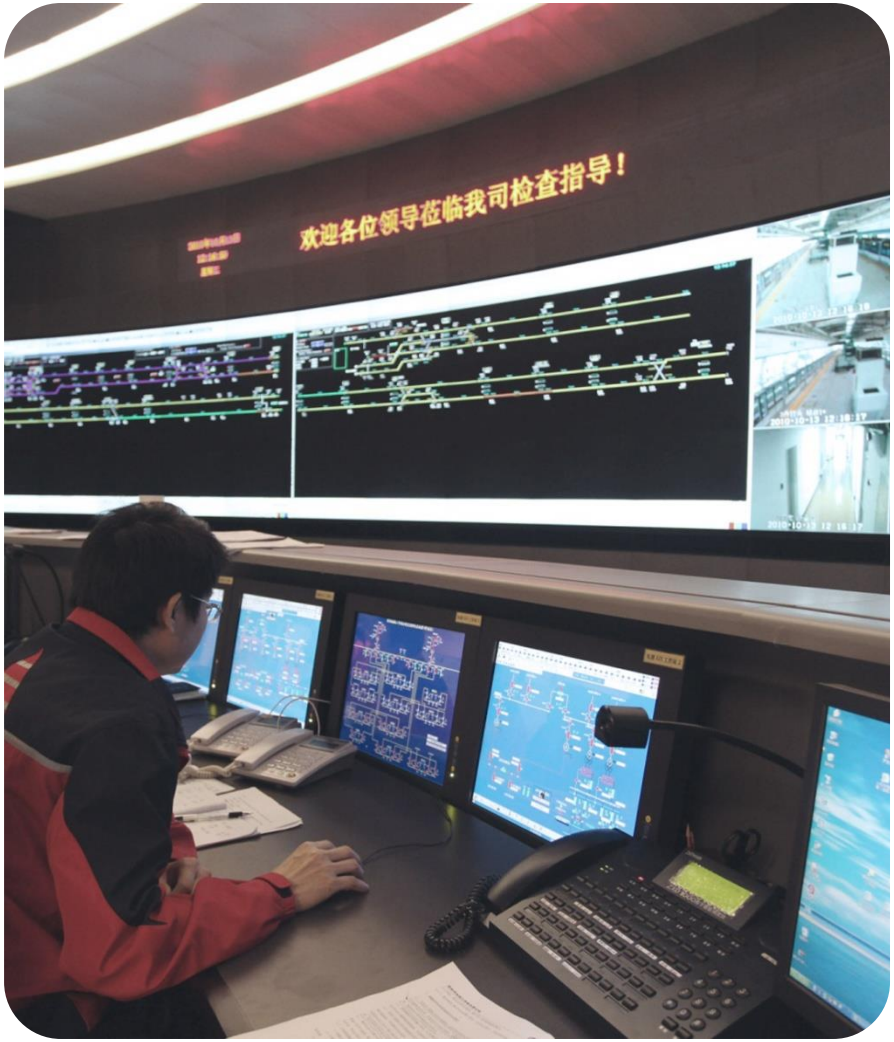
FULLY AUTOMATED DRIVERLESS OPERATION

CITYFLO 650 technology

- **Proven technology**
- **Reduces cost of operation**
- **Reduces system maintenance costs**
- **Minimises energy consumption**
- **Allows for very short headways, which enable:**
  - maximum train speed
  - minimum train lengths
  - minimum platform length and civil station costs
  - optimum fleet size
  - minimum wait times (higher frequency of service)
  - high ridership levels



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OPTIMISED SYSTEM FOR MASS TRANSIT APPLICATIONS

Vehicle overview

Train configuration	2- to 8- car trains
Car empty weight	14,000 kg
Maximum gradient	6%
Minimum horizontal curve radius	46 m
Maximum speed	80 km/h
Power distribution	750 Vdc
Propulsion system	Permanent Magnet Motor
Design capacity	
▪ 2-car trains	9,680 pphpd[1]
▪ 4-car trains	20,400 pphpd
▪ 8-car trains	41,840 pphpd

[1] pphpd : passengers per hour per direction
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BUILT TO THE HIGHEST QUALITY STANDARDS

Vehicle overview

- **Aluminium carbody, steel underframe, composite end cap**
- **Independent bogie with secondary suspension**
- **Tinted windows with laminated safety glass**
- **2 bi-parting doors per side of car**
- **Roof-mounted air conditioning units with containing twin HVACs**
- **Complies with NFPA for fire safety**

[1] NFPA

FOCUS ON PASSENGERS

Vehicle interior

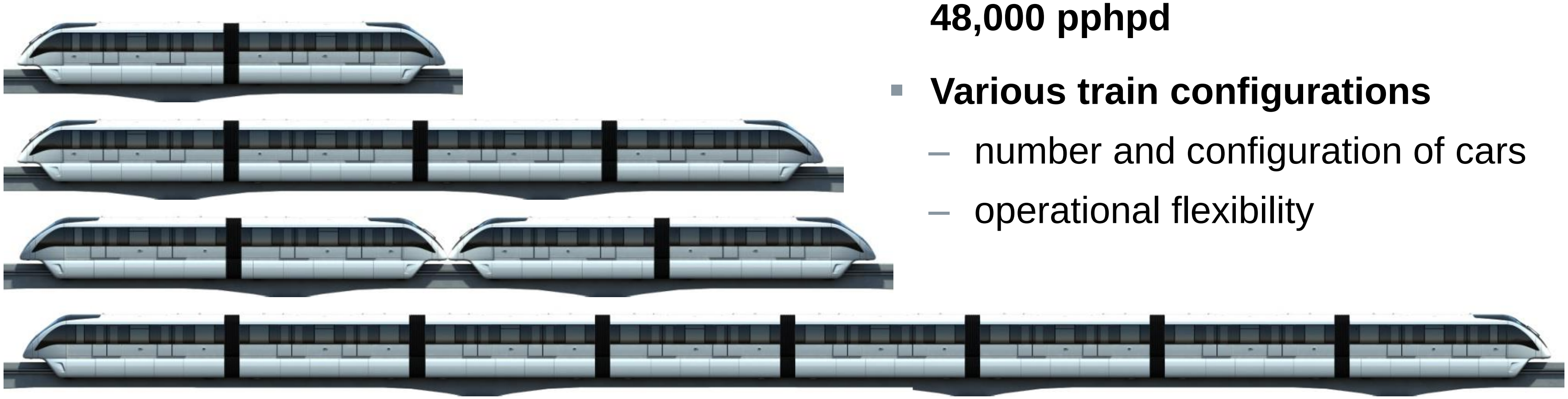
- **Spacious and open vehicle increase passenger comfort**
- **Superior ride quality through independent bogies**
- **Inter-car walk-through provides free passenger flow and enhanced safety**
- **Large windows create bright atmosphere and unique view of city**
- **Low interior noise enhances the ride experience**
- **Passenger information system for clear and timely instruction**
- **Accessible for passengers with disabilities**

HIGH FLEXIBILITY AND CUSTOMISATION

Tailor-made vehicles

- **Customisable exterior design**
- **Flexible interior arrangements**
  - wide choice of colors and materials
  - configurable seating
  - spacious interiors and gangway
- **Customisable static and dynamic signage**

- **Solutions from 2,000 to 48,000 pphpd**
- **Various train configurations**
  - number and configuration of cars
  - operational flexibility



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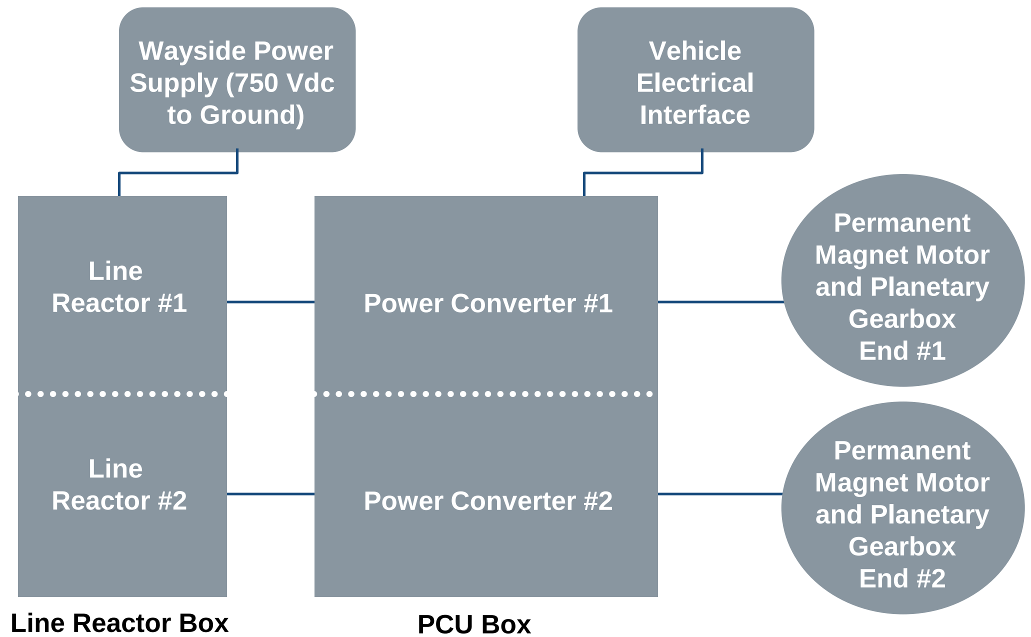
DRIVEN BY INNOVATION AND INGENUITY

Propulsion technology

- **Permanent magnet motor (PMM) designed for *INNOVIA* Monorail 300 system**
- **Rotor creating its own flux by incorporating magnets**
- **Propulsion system maximizing regenerative dynamic braking to minimise use of friction brake**



- **Speeds up to 80 km/h**
- **High capacity transit**
- **Low noise**

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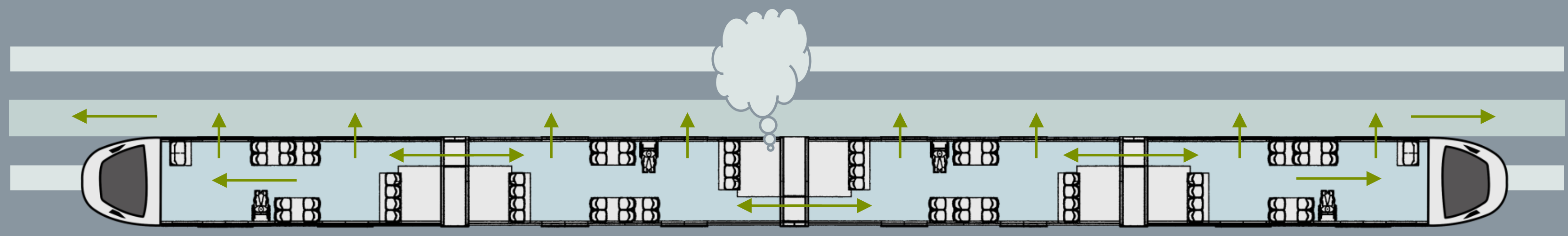
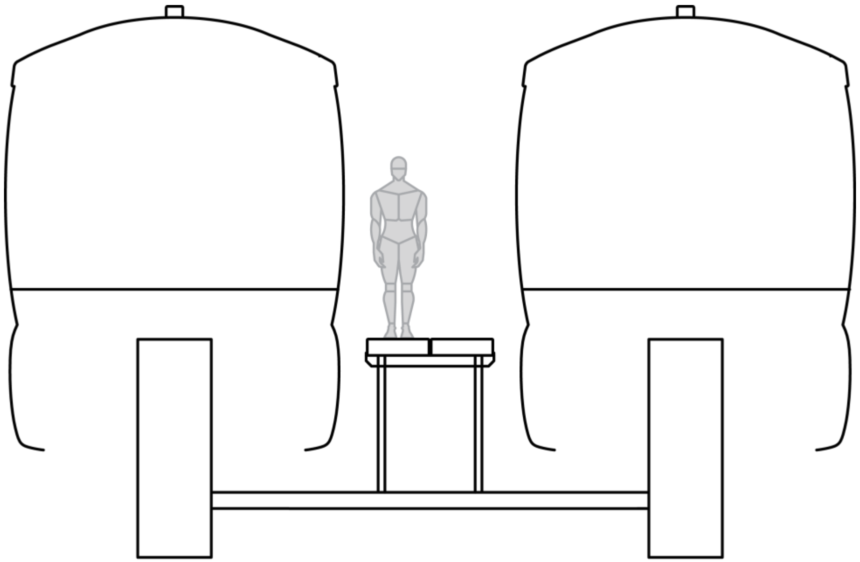
ENHANCED SAFETY WITH UNCOMPROMISED AESTHETICS

Evacuation walkway

Immediate, rapid passenger initiated evacuation from a hazardous situation





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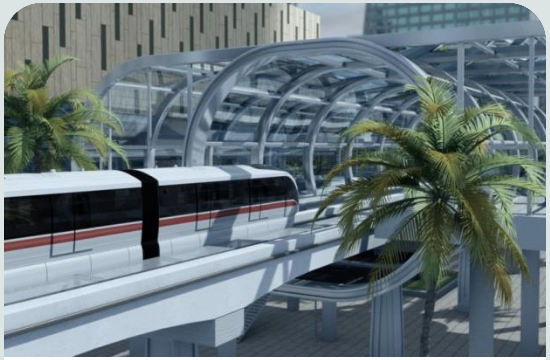
FLEXIBLE ALIGNMENT WITH MINIMUM VISUAL IMPACT

Guidebeams



Concrete structures provide elegant strength and durability as well as:

- **Fast and efficient construction**
- **Affordability**
- **Fire-resistance**
- **Low maintenance**
- **Full compliance to all norms and standards**

Exclusive guidebeams ensure:

- **Dedicated right-of-way unrestricted operation**
- **Accidents with surface traffic are impossible**
- **Derailment virtually impossible**

Unobtrusive evacuation walkway, always recommended for safe egress, allow for:

- **Passenger safety**
- **Easy access for system maintenance**
- **No need for active intervention in an emergency**

COST EFFECTIVE AND EASY INSTALLATION

Guidebeams

- **Infrastructure developed to minimise the cost and disruption of civil construction**
- **Pre-cast lightweight guideway structures built off-site allow rapid assembly on site**
- **Low land intake / low expropriation costs reduce delays and allow for quick progress**
- **Elevated guideway eliminates the need for expensive and time-consuming tunnelling**
- **Easy implementation into different environments (suitable for both greenfield and brownfield)**

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FAST AND SMOOTH SWITCHES

Guidebeams

- **Beam replacement or multi-position pivot switches**
  - beam replacement switches are used on the mainline
  - multi-position pivot switches are used in storage yard areas
- **No restriction of system capacity or operating speed**

High speed beam replacement turn out switch

Multi-position pivot switch

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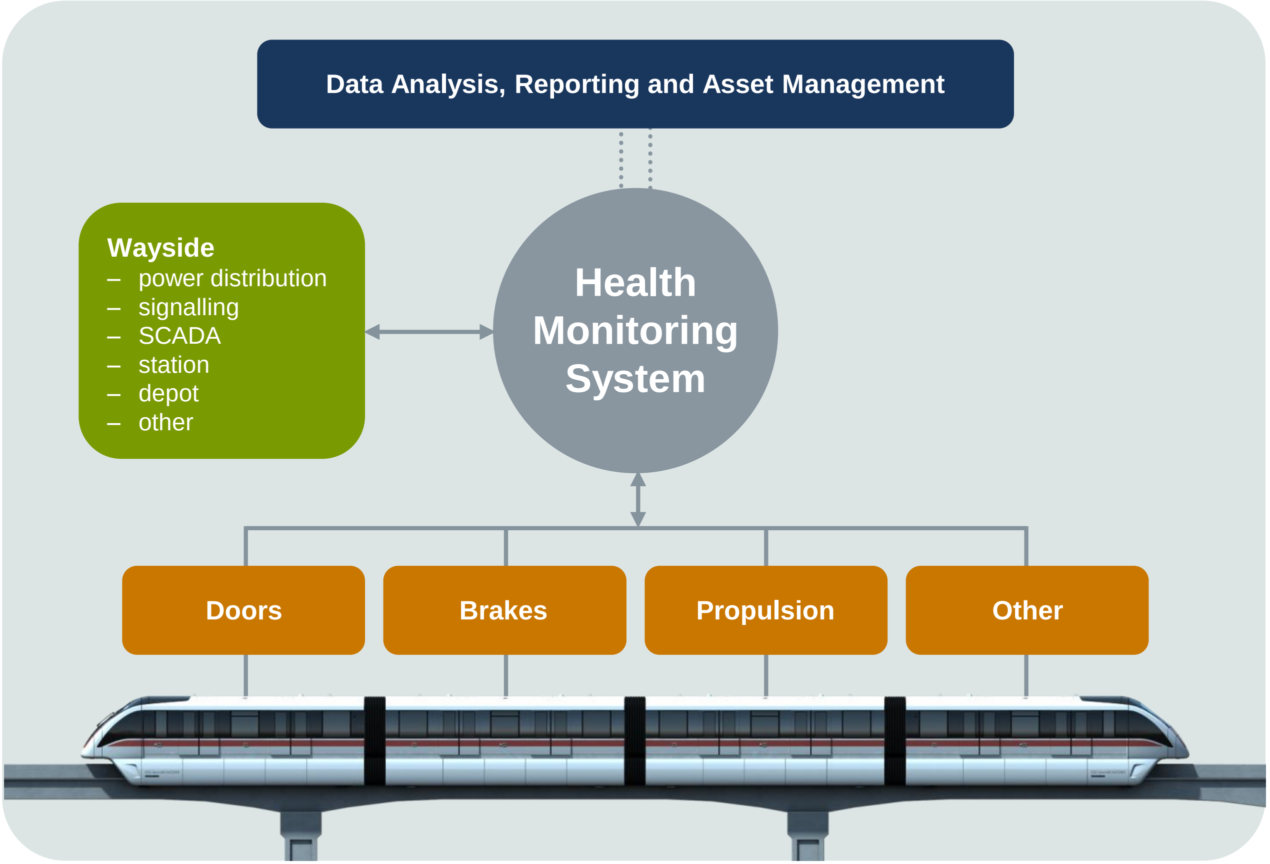
DYNAMIC ASSET MANAGEMENT SERVICES

Operation and maintenance (O&M)

New developments in embedded diagnostic systems for vehicle subsystems and wayside systems

- **Collect and analyse data**
- **Data trending and visualisation**
- **Deep visibility into performance**
- **Fast fault finding and resolution**



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PREDICTIVE MAINTENANCE

Operation and maintenance (O&M)

Increase availability

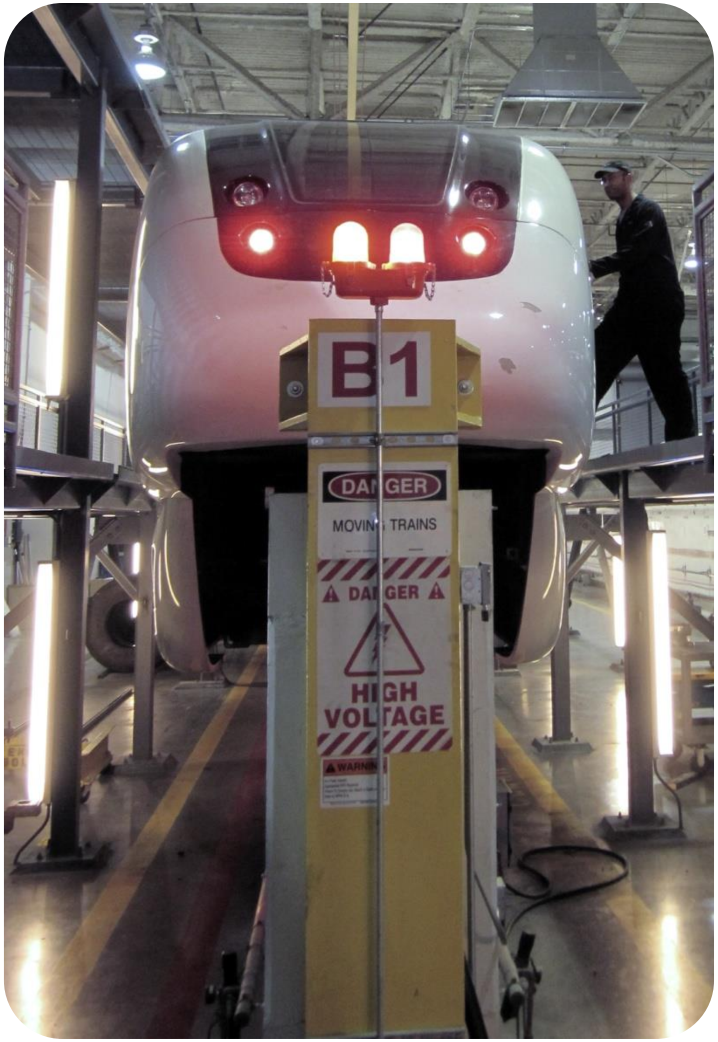
- Minimise service affecting failures
- Track failure trends and mitigate

Improve customer service

- Perform maintenance optimally
  - extends the operating life of the system
  - extends life of equipment

Reduce the total cost of ownership

- Extends maintenance intervals
- Potential elimination of daily/monthly tasks
- Automated vehicle inspections
- Reduce planned maintenance activities
- Reduce spares holdings



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PROVEN TRACK RECORD OF SAFE OPERATIONS

Safety features

- **Driverless operation eliminates risk of human error**
- **Emergency walkway along entire guideway allows safe egress for passengers and safe access to guideway for maintenance crew**
- **Inter-car walk-through enhances passenger safety**
- **Platform screen doors increase station safety, as well as provide climate control**
- **Two-way radio with central control and CCTV cameras on-board and in stations**
- ***SEKURLFO* transit security solution enables operators to protect passengers and property efficiently and cost-effectively**
- **Conservative system design with careful analysis of safe stopping distances**

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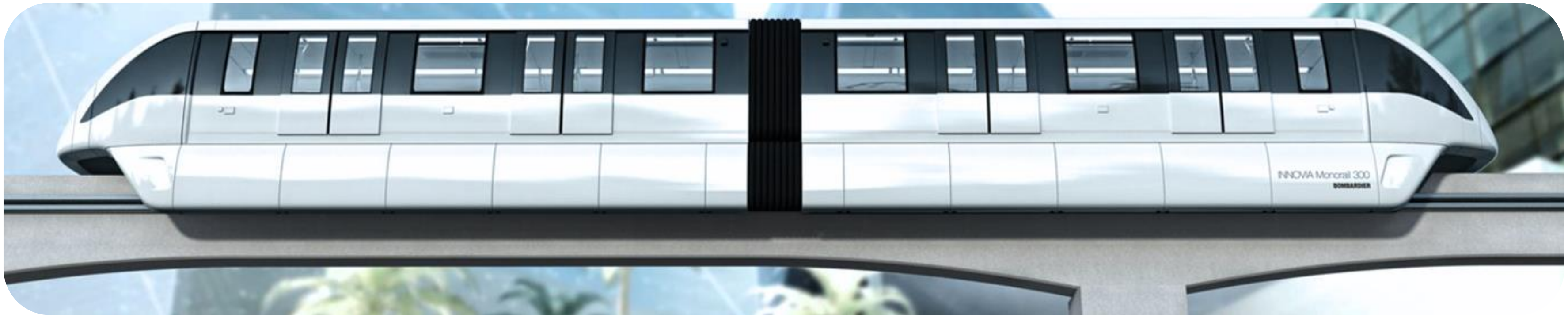
LOW SYSTEM AND FLEET COSTS

Lifecycle perspective



- **Lightweight aluminium vehicles reduce energy consumption costs**
- **Standardised for optimised operation and maintenance costs**
- **Driverless operation provide requires less staff and reduces overhead costs**
- ***CITYFLO* 650 automated train control also reduces the costs of service interruptions and corrective maintenance**

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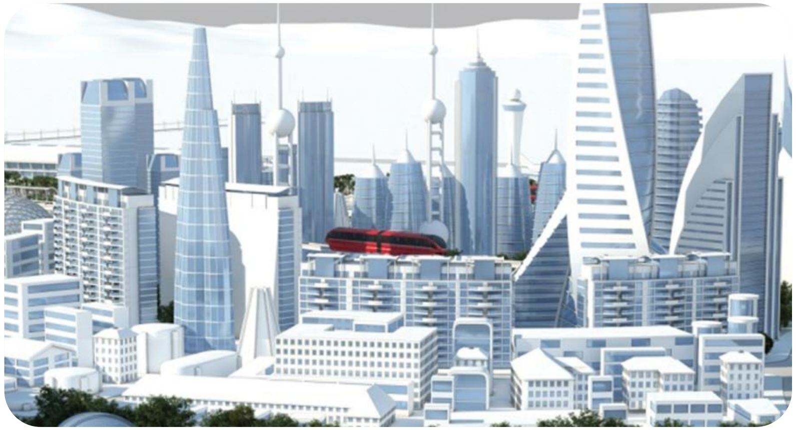
ECO-FRIENDLY SOLUTION

Design for environment

- **Zero emissions**
- **Lightweight aluminium vehicles designed for optimal energy consumption**
- **Intelligent Power Management System**
  - energy efficency
  - optional *EnerGstor* wayside storage for enhanced energy savings
  - *EnerGplan* simulation tool for optimised energy consumption
- **Minimised consumption of construction materials**
- **Low visual impact, easily fits into existing infrastructure**
- **Low exterior noise**
- **Requirements for all suppliers**
  - maximised use of recyclable materials
  - use of environmentally friendly refrigerant



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ENERGY EFFICIENCY

Design for environment

System energy usage optimised through:

- **Aerodynamic, lightweight aluminium vehicles**
- **High percentage of recyclable materials**
- **LED lighting**
- **Automatic train control**
- **Efficient permanent magnet motor propulsion technology**
- **Improved vehicle thermal insulation system**
- **Regenerative braking**
- **Intelligent power management system**
- **Minimal consumption of construction materials**

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WAYSIDE STORAGE SYSTEM

Design for environment

Based on modular supercapacitor technology for wayside, the new *EnerGstor* solution provides both economic and environmental benefits.

- Simple interface
- No house power connection required
- No communications connection required
- Only connections are to traction power +ve, -ve and ground

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Artist rendering does not reflect the subtly of the *EnerGstor* unit in colour or location

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ENERGY OPTIMISATION SYSTEM

Design for environment

***EnerGplan* Simulation Tool allows the power supply and distribution (PS&D) engineer to optimise the power system configuration, minimise the energy consumption of the entire transit system, and overall analysis of system performance.**

- Graphical interface modelling of fleet energy consumption and operational data
- Combination of energy consumption and operational data into effective management information
- Adaptable to all kinds of vehicles and transportation systems
- Sophisticated analytical tools for comparative fleet analysis to guide

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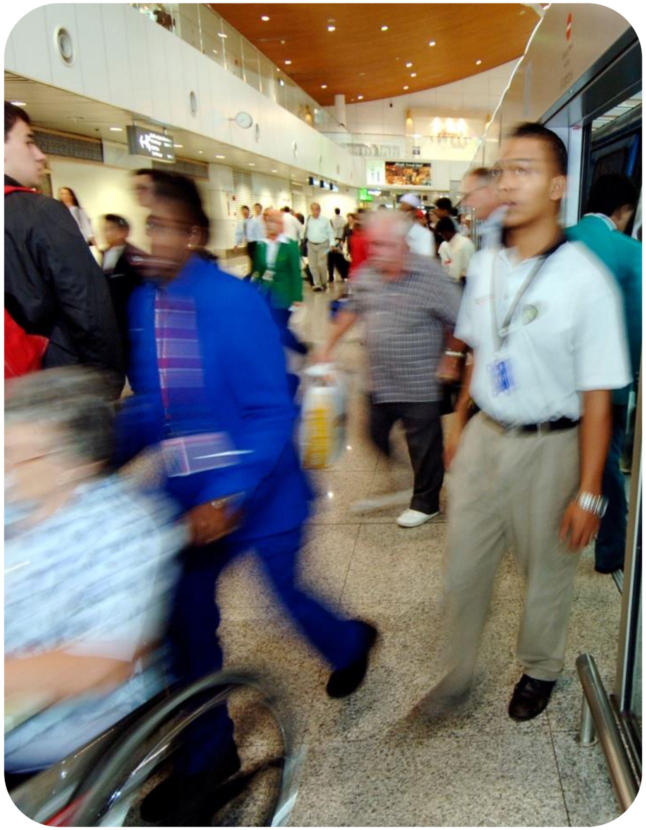
INCREASING SYSTEM CAPACITY

Future expansions

- ***INNOVIA* Monorail 300 systems can easily accommodate future expansions**
- **Future expansions should be considered in the initial planning stage, but the flexible system design allows for unanticipated extensions and additions**
- **System expansions can be implemented without disrupting passenger service**
- **Expansions can include:**
  - adding new vehicles to an existing system
  - additional vehicles, sections of guideway and stations
  - signalling upgrades and overlays
  - spur lines
  - new operations and maintenance facilities or upgrades to the existing depot



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SUMMARY OF BENEFITS

INNOVIA Monorail 300 system

Technology	▪ Sleek and attractive vehicles ▪ Slender contemporary guidebeams have a subtle presence ▪ Unique emergency walkway allows for safe passenger egress ▪ Modern solution to transportation needs
Operation	▪ Driverless system enhances overall efficiency ▪ Frequent, safe and reliable service ▪ High service capacity ▪ Cost effective transit solution
Passenger	▪ Modern visual appeal ▪ Spacious vehicle interior ▪ Easy access for passengers ▪ Comfortable rides
Environment	▪ Low visual impact ▪ Low noise ▪ Zero emissions ▪ Energy saving equipment

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TWENTY YEARS OF URBAN MOBILITY EVOLUTION

Reference projects

Riyadh, Saudi Arabia
INNOVIA Monorail 300 System
In delivery

São Paulo, Brazil
INNOVIA Monorail 300 System
2014 (Phase 1)

Las Vegas, USA
INNOVIA Monorail 200 System
2004

Jacksonville, USA
INNOVIA Monorail 100 System
1998

Newark, USA
INNOVIA Monorail 100 System
1996

Tampa, USA
INNOVIA Monorail 100 System
1991

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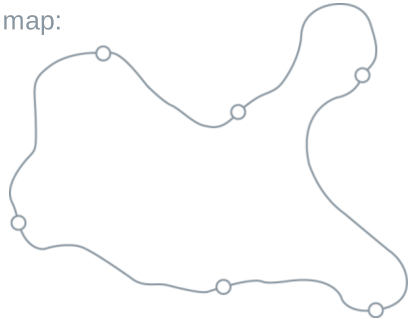
RIYADH, SAUDI ARABIA

INNOVIA Monorail 300 system

System alignment map:



- **Primary transportation at the new King Abdullah Financial District**
- **In delivery**
- **3.6 km single-beam alignment**
- **6 stations**
- **12 cars (6 two-car trains)**
- **Designed to carry 3,000 pphpd**
- **5.7% maximum grade**
- ***CITYFLO* 650 automatic train control**
- **Bombardier will provide operations and maintenance services**

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SÃO PAULO, BRAZIL

INNOVIA Monorail 300 system

System alignment map:

- **Vila Prudente to Cidade Tiradentes urbanization – extension of the São Paulo Metro Line 2**
- **Revenue service for Phase 1 began in 2014**
- **24 km dual-beam alignment**
- **17 stations**
- **378 cars (54 seven-car trains)**
- **Designed to carry 40,000 pphpd[1]**
- **6% maximum grade**
- ***CITYFLO* 650 automatic train control**

[1] Fleet expansion required to realise full system ridership capacity of 48,000 pphpd

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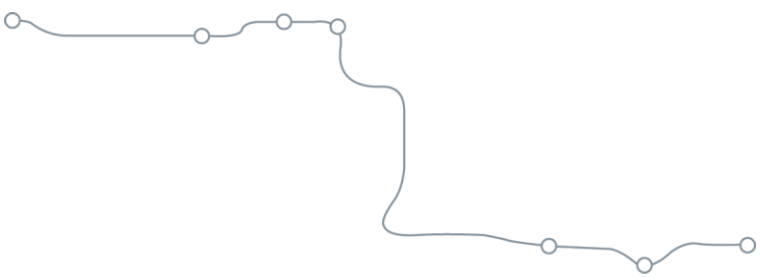
LAS VEGAS, USA

INNOVIA Monorail 200 system

System alignment map:



Serves the famous Las Vegas Strip – Sahara to MGM Grand, including Las Vegas Convention Center

Revenue service began in 2004

6.5 km dual-beam alignment

7 stations

36 cars (9 four-car trains)

Designed to carry 3,200 pphpd

6.5% maximum grade

750 Vdc guideway-mounted power rails

Public Private Partnership

Bombardier provided 10 years of operations and maintenance services

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JACKSONVILLE, USA

INNOVIA Monorail 100 system

System alignment map:

Downtown Jacksonville – both sides of the St. Johns River

Revenue service began in 1998

5 km dual-beam alignment

8 stations

9 trains

Designed to carry 900 pphpd

8% maximum grade

Guideway-mounted power rail

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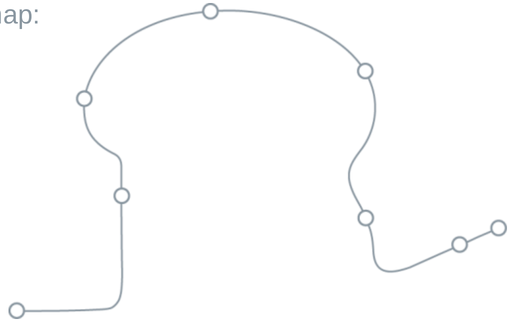
NEWARK, USA

INNOVIA Monorail 100 system

System alignment map:



- Newark Liberty International Airport – airport terminals to northeast corridor rail line
- Revenue service began in 1996
- 4.7 km dual-beam alignment
- 8 stations
- 108 cars (18 six-car trains)
- Designed to carry 3,000 pphpd
- 3.9% maximum grade
- Guideway-mounted power rail
- System expanded in 2001
- Bombardier provides operations and maintenance services

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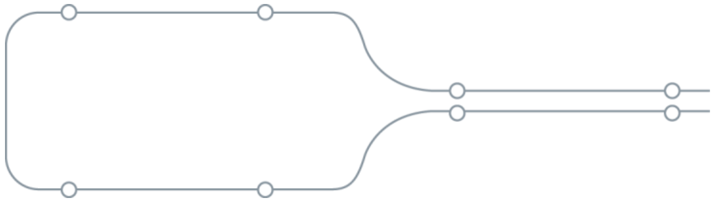
TAMPA, USA

INNOVIA Monorail 100 system

System alignment map:



- **Tampa International Airport – parking garage to main terminal**
- **Revenue service began in 1991**
- **1 km dual-beam alignment**
- **8 stations**
- **6 trains**
- **Designed to carry 680 pphpd (with luggage)**
- **Bombardier provides maintenance services**

INNOVIA is a trademark of Bombardier Inc. or its subsidiaries.

BOMBARDIER
the evolution of mobility

BOMBARDIER

the evolution of mobility

APPENDIX – B.2 BYD MONORAIL MARKETING

BYD SKYRAIL

State-of-the-Art, Driverless Monorail

BYD's SkyRail is a fully integrated, driverless, state-of-the-art straddle type monorail system that incorporates all of the features needed for rigorous line-haul urban transit applications.

The elevated fixed guideway means there are no at-grade passenger or vehicle collisions.

SkyRail is compliant with all applicable codes and standards, including NFPA 130 and ASCE 21 specifications.

BYD's Iron phosphate batteries are installed in all trains so in the event of a regional power outage, trains can still operate to the nearest station to safely discharge passengers. It also means that power rails are not required in maintenance facilities, greatly reducing electrical arcing risk to maintenance personnel.

SkyRail can be, and already is, constructed far faster, with far less impact, and less costly than any other comparable urban transit system technology because:

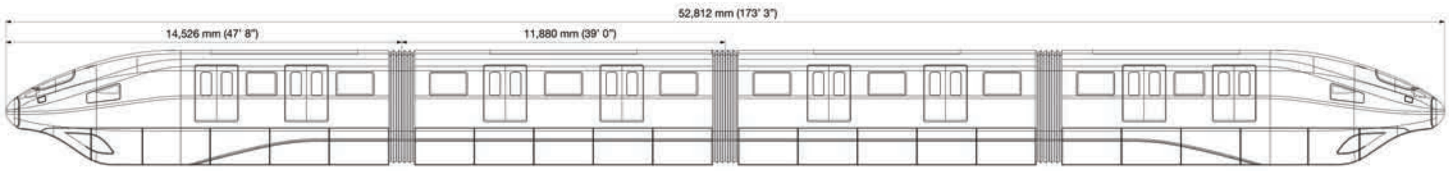
- It uses the smallest, lightest weight aerial structure
- Unlike any other comparable technology, SkyRail's aerial structure provides both the structural support as well as guidance for vehicles in a single guidebeam.
- This makes the footings much smaller and easier to fit into congested corridors with fewer utility relocations, while minimizing costly, time-consuming, and often contentious property acquisition.
- Uses pre-cast structural elements – including columns and beams – which greatly speeds the construction process and minimizes traffic and community disruption.
- As a result, SkyRail is much less costly to construct than conventional elevated technologies and a fraction of the cost of subways.

SkyRail's wide carbody and walk through design facilitates seamless ingress, egress and passenger flow through the train.

Configurable in up to an 8-car fixed consist, or smaller consists coupled automatically, SkyRail systems can move up to 37,200 people per hour per direction with trains operating on two minute scheduled headways (18,780 at U.S. standing space standards).

SkyRail incorporates the 60 years of evolutionary improvements found in other forms of rail transit, including: proven guide-beam switching utilizing transit grade components, state-of-the-art communications based, moving block train control, 5.8 GHz wireless communications, on-board Wi-Fi, and wayside battery energy storage.

Build Your Dreams



	BYD SKY RAIL	HIGH SPEED AUTOMATED MONORAIL
Vehicle Data	Type of Vehicle	BYD SkyRail
	Maximum train consist	2-to 8-car trains
	Automatic coupling	2 to 8 car consists form 4, 6, or 8-car trains
Dimensions and Weight	Length (end car overall)	14,525 mm(47'8")
	Length (end car over coupler)	14,050 mm(46'1")
	Length (mid car)	11,880 mm (39' 0")
	Width (overall)	3,165 mm (10' 5")
	Rooftop to top of running surface	3,020 mm (9' 11")
	Doorway width (clear opening)	1,300 mm (51")
	Doorway height (at threshold)	1,850 mm (73")
	Wheelbase (centerline to centerline)	9,114 mm (29' 11")
	Vehicle weight empty (average)	14,000 kg (30,856 lb)
Technical Characteristics	Power distribution	750 Vdc or 1500 Vdc
	Propulsion system	3-phase AC permanent magnet synchronous motor, 2 per car
	Backup propulsion system/Maintentance facility propulsion	on-board rechargeable BYD iron-phosphate batteries
	Vehicle guidance	straddle beam monorail
	Vehicle operation	bi-directional
	Braking	regenerative/friction
	Energy storage	wayside containerized battery energy storage, BYD iron-phosphate batteries
	Suspension	pneumatic spring, self leveling load
	Bogies	2 single axle dual load tires per car with lateral guidance tires
	Carbody	aluminum carbody, steel underframe, composite end cap
	Windows	tinted, single glazed
	Doors	2 bi-parting doors per side per car
	Air-Conditioning	Roof-mounted module containing twin HVAC units
	Fire safety design	floor rating meets ASTM E-119, NFPA 130 compliant
Performance and Capacity	Maximum operating speed	120 km/h (75 mph)
	Nominal cruising speed	105 km/h (65 mph)
	Acceleration rate (service)	1 m/s2 (3.28 ft/s2)
	Brake rate	1 m/s2 (3.28 ft/s2)
	Minimum horizontal curve radius	46 m (150')
	Maximum sustained gradient	10%
	Recommended maximum gradient	6%
	Wheelchair locations	2 per car (flexible)
	Passenger seats per car	
	Perimeter (end car, mid car)	16, 16 (flexible)
	4-across (end car, mid car)	20, 16 (flexible)
	Vehicle capacity (standees + seated) (4-car train, 4-across seating)	
	@ 4 pass./m^2	238 + 72 = 310
	@ 9 pass./m^2	536 + 72 = 608
	Design capacity (4 standees/m^2 / 9 standees/m^2)	
	2-car trains at 2 min scheduled headways	4,560 pphpd / 8,760 pphpd
	4-car trains at 2 min scheduled headways	9,300 pphpd / 18,240 pphpd
	8-car trains at 2 min scheduled headways	18,780 pphpd / 37,200 pphpd

BYD NORTH AMERICA

1800 S Figueroa St.
Los Angeles, CA 90015

Tel +1 (213) 748-3980

en.byd.com/skyrail
skyrail.us@byd.com

SKYRAIL

Build Your Dreams®

BYD Company Limited ("Build Your Dreams")

BYD COMPANY OVERVIEW

BYD is a pioneer and global leader in achieving a Zero Emission Energy Ecosystem, offering affordable solar power, reliable energy storage, and electrified transportation. Founded in February 1995, **BYD is a private (non-government owned or controlled) company** that has grown from a start-up rechargeable battery manufacturer into a company with **220 thousand employees** today and 2018 revenues of over $19.4 Billion. Throughout its 24 years of high-speed growth, BYD has established **over 30 industrial parks** across **six continents** and has played a significant role in industries related to electronics, automobiles, new energy and rapid transit. From energy generation and storage to "green" energy applications, BYD is dedicated to providing one-stop zero-emission energy solutions.

BYD is now one of the world's largest manufacturer of rechargeable batteries and battery-electric vehicles, selling more than **50,000 pure battery-electric buses, 8,000 electric trucks,** and **20,000 electric forklifts**. In addition, for four years in a row (2015-2018), BYD has been ranked **No. 1** on the global new energy vehicles (NEV) market, which includes plug-in hybrid and pure electric automobiles.

BYD's global transportation strategy is designed to address the climate crisis, increasing air pollution, and worsening traffic congestion from rapid urbanization. The universal adoption of electrified vehicles can reduce the consumption and dependence on fossil fuel, and further reduce the greenhouse gases emission. As such, BYD has focused on the mass-market adoption of zero-emission, battery-electric vehicles. BYD's initial efforts focus on transit buses, coaches, taxis, consumer vehicles, logistic vehicles, construction vehicles, and waste management vehicles; with a specific focus on vehicles in the warehouse, mining, airport, and port & terminal environments.

An ongoing innovator and investor, BYD owns **15,000+ patents**, and has applied for 24,000 patents globally. BYD's stock is publicly traded on the Hong Kong Stock Exchange, its annual reports and stock ownership are reported publicly in our annual reports, and Berkshire Hathaway, based in Nebraska, is the largest public shareholder of BYD's H-Shares. Throughout the world, we are committed to our BYD mission: **"technological innovations for a better life."**

BYD SKYRAIL

To further expand our global clean mobility initiative, BYD invested seven years and $ 2.2 billion on automated rapid transit system development, including $700+ million on SkyRail. This autonomous straddle-type monorail system is a cost-effective alternative to traditional subway and light rail systems for addressing traffic congestion problems in urban areas. It has strong advantages, including high-capacity, high-speed, driverless operation, and an iconic, progressive image that is much more compatible with the urban fabric than any other elevated alternative..

SkyRail can be constructed far faster, with far less impact, and is much less costly than any other grade-separated urban transit system, primarily because its narrow pre-cast guide beams both support and guide the vehicles, thereby requiring a fraction of the concrete and steel (and labor hours) to construct than any other elevated technology. SkyRail systems can move nearly 19,000 passengers per hour per direction (pphpd) at U.S. standing space standards, at speeds up to 75 mph, with wide, walk-through trains operating on two-minute scheduled headways. SkyRail incorporates the 60 years of evolutionary improvements found in other forms of rail transit.

To date, BYD has conducted feasibility studies in over 100 large cities and metropolitan areas around the globe. Under a single point of responsibility for project delivery, BYD aleady has constructed five SkyRail projects since publicliy announcing the technology in 2016. In 2019, BYD signed the final agreement for our newest SkyRail Project: SkyRail Bahia – a 12.4 mi SkyRail system in Salvador, Brazil; and construction will commence in Q1 2020.

BYD SKYSHUTTLE

BYD's SkyShuttle is the world's first rechargable, battery-electric, grade separated, autonomous, sustainable, and higher speed solution to the"First Mile/Last Mile" and short urban line haul challenge that all cities face in striving to create a viable mobility alternative to the private automobile. SkyShuttle was developed specifically to meet this challenge through the full integration of electric propulsion and guidance components proven in our electric bus and SkyRail programs as the world's leading provider of green, sustainable, fully integrated transportation systems.

The simple low cost, low profile, modular pre-fabricated elevated structure supports attractive small vehicles that can operate as a single car or in trains at very high frequencies (every 90 seconds), at speeds up to 50 mph (80 km/hr), providing a peak hour carrying capacity of up to 12,000 pphpd (again, at U.S. standing space standards). No costly and risky underground construction is required.

A COMMITMENT TO LOCAL MANUFACTURING AND MEANINGFUL JOBS

BYD's partnership with the City of Lancaster, California, Los Angeles County, helped launch and grow the firm's battery-electric vehicle business in North America.

- ✓ The company is now **the largest manufacturing employer in Lancaster** as well as one of the largest renewable energy employers and private sector employers in Los Angeles County.
- ✓ BYD Lancaster staff: 750 (625 production); with a **diverse workforce (comprised of 85% minorities);** includes veterans and a growing number of women and second chance employees, all achieved in cooperation with Jobs to Move America.

- ✓ The only pure electric vehicle manufacturer in the U.S. with an all-union workforce.
  - **Exceeding Buy America**, as verified by ongoing FTA audits
- ✓ First opened in 2013, our Lancaster plant's last expansion, completed in 2017, created a:
  - **Quadrupling of our manufacturing plant** size to 446,000 square feet;
  - **60% increase in jobs** from 500 to more than 750;
  - **25% increase in annual revenue for the City of Lancaster**; and
  - **35% increase in overall jobs supported annually in the area**.
- ✓ BYD North America's **state-of-the-art manufacturing plant is ISO 9001 Certified.**
- ✓ BYD's 100,000 square-foot warehouse opened in 2018 providing more space to produce and deliver our vehicles. The addition grew the **plant's overall footprint to 556,000 square feet**.

BYD'S COMMITMENT TO LOCAL MANUFACTURING FOR SKYRAIL AND SKYSHUTTLE

BYD also is fully committed to manufacturing SkyRail and Sky Shuttle vehicles in Los Angeles County.

- ✓ BYD has **purchased another 154 acres in Lancaster** for the manufacturing of SkyRail & SkyShuttle vehicles and systems. The land is in the design and permitting stage, and is estimated to create up to 1000 jobs alone, just for creation of the facilites.
- ✓ BYD is fully committed to achieving or exceeding the same minority, disadvantaged, women, and veteran participation goals it has achieved for the existing electric bus and truck plant.

BYD Transit Solutions LLC. is a wholly-owned subsidiary of BYD Company Limited. BYD SkyRail was established for the primary purpose of implementing and operating BYD SkyRail and Sky Shuttle systems in North America. Its performance is backed and guaranteed by the parent company.

Build Your Dreams®

SkyRail Project List						
No.	Name of Project	Geographic Information		Alignment		Project Status
		Country	City	Length (mi)	# of Stations	
1	Pingshan Campus	China	Shenzhen	2.7	3	In Operation
2	Yinchuan Flower Garden		Yinchuan	3.5	8	In Operation
3	Guang'an SkyRail		Guang'an	6.8	7	Final Testing & Commissioning
4	Jining SkyRail		Jining	5.9	6	Final Testing & Commissioning
5	Shantou SkyRail		Shantou	3.1 + 9.1	4 + 11	Constructed + In Planning
6	Bahia State SkyRail	Brazil	Salvador	12.4	19	Construction Starting in Mid 2020
7	Transbay Connector	United States	Undisclosed - South Florida	3.5+	3+	In Planning
8	Intermodal Multi-Venue Connector		Undisclosed - Southern California	1.9	4	In Planning
9	Intermodal Venue Connector		Undisclosed - Southern California	1.5	2	In Planning
10	Regional Mass Transit Corridor		Undisclosed - Southern California	19	8+	In Planning

Constructed SkyRail Project Photos

Shenzhen

- 2.7 mi, operation in pinched-loop configuration
- 3 stations

Build Your Dreams®

Yinchuan

- 3.5 miles, operation in open loop configuration
- 8 stations


3A111
迎乘坐比亚迪云

Build Your Dreams®

Guang'an, China:

- 6.78 mi, pinched-loop operation
- 7 stations


人民有信仰
民族有希望
国家有力量
学习雷锋
助人为乐

Jining, China

- 5.93 mi, pinched-loop operation
- 6 stations

Shantou

First Phase:

- 3.1 mi, pinched loop operation
- 4 stations

Second Phase (Not Yet in Construction):

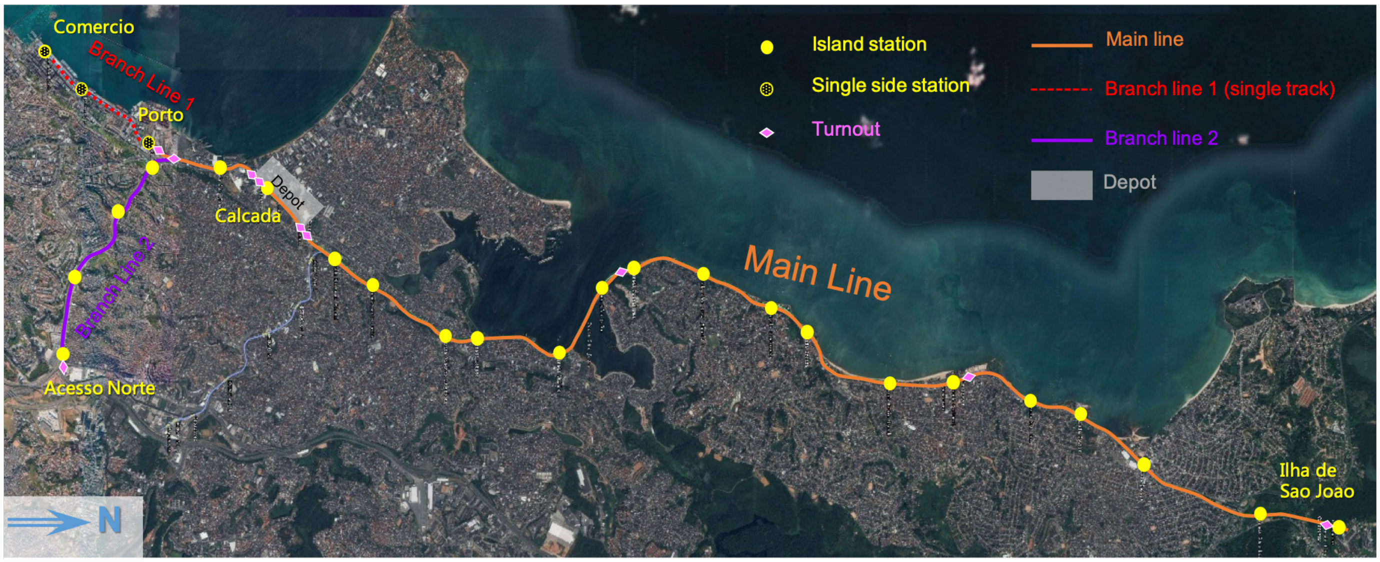
- 9.1 mi, 11 stations


汕头大学
SHANTOU UNIVERSITY


大發

Salvador, Brazil

- 12.4 mi, 19 stations
- Construction starting in mid 2020
- Project involves:
  - Property development rights near stations
  - Retrofit of existing freight rail bridge over water crossing



APPENDIX – B.3 CRRC MONORAIL MARKETING

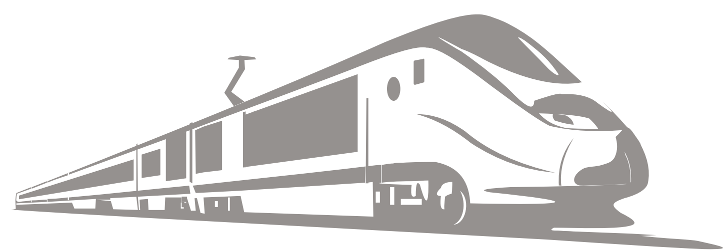
中国中车
CRRC

Series Products of New Generation Straddle Monorail Vehicle of CRRC Changchun

中车长春轨道客车股份有限公司
CRRC CHANGCHUN RAILWAY VEHICLES CO., LTD.
重庆中车长客轨道车辆有限公司
CHONGQING CRRC RAILWAY VEHICLES CO.,LTD.

www.crrcgc.cc

Contents



CRRC

I. Development of Straddle Monorail Vehicle

Development of Straddle Monorail Vehicle of CRRC Changchun

- First generation introduced monorail vehicle
- Structure of 4-car marshaled vehicle

Technology introduction

Digestion and absorption

2004

- Second generation large-sized monorail vehicle developed independently
- Structure of 4,6,8-car marshaled vehicle

Independent research and development
Full realization of localization

2009

- New generation Straddle monorail vehicle
- Serialized products

Serialization, intelligence and lightweight
Application of advanced technology

2016

After more than 10 years of continuous development, CRRC Changchun Monorail has undergone a process from technology introduction to completely independent innovation, and has formed a platform-based and diversified monorail vehicle product series.

I. Development of Straddle Monorail Vehicle

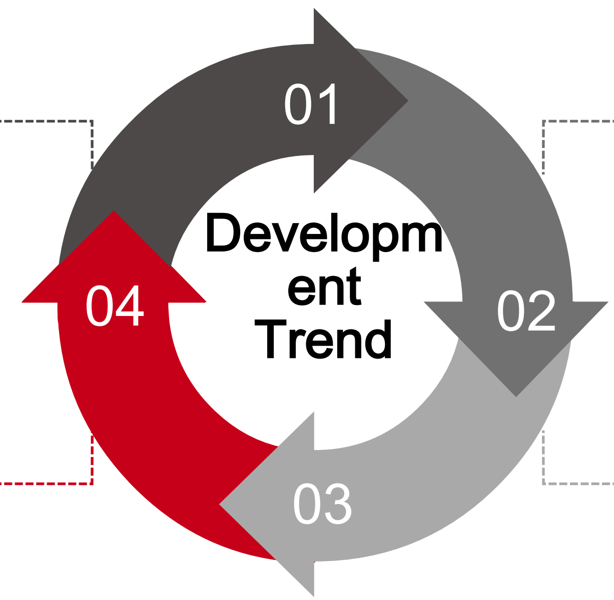
Development Trend of Straddle Monorail Vehicle

Diversification

Diversified and customized vehicle configuration and modeling design meet the different operational needs of users.

Intelligence

Achieve unmanned vehicle driving, automatic fault diagnosis, as well as operation and maintenance analysis and management through the high-speed intelligent system.



Humanization

People-oriented high-standard safe operation configuration and selection of green vehicle materials to achieve safe and green application of vehicles.

Lightweight

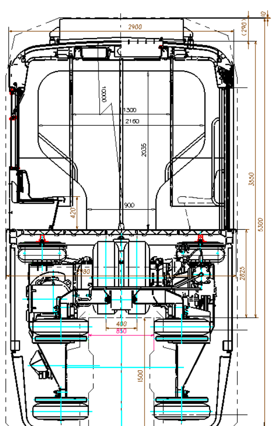
Modular and integrated design, lightweight structure construction, and selection of lightweight materials to achieve reduction of vehicle energy consumption.

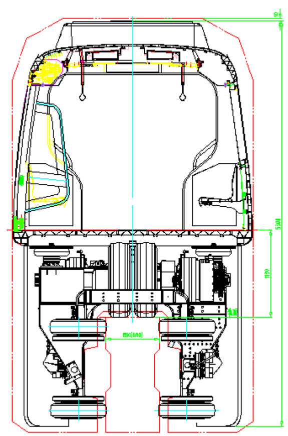
CRRC

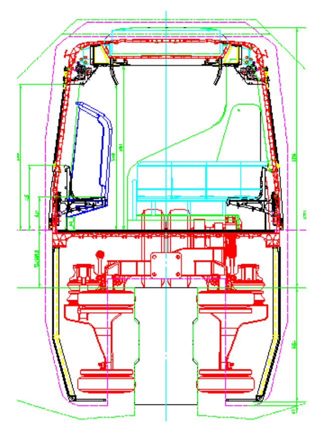
II. Introduction to Straddle Monorail Vehicle of CRRC Changchun

1. Straddle Monorail Platform Series Product of CRRC Changchun

- The platforms of Straddle Monorail Technology Division of CRRC Changchun Railway Vehicles Co., Ltd. have a full range of products. Its large, Small and Medium and small vehicles can meet the selection needs of different users.







CRRC

II. Introduction to Straddle Monorail Vehicle of CRRC Changchun

2. Realization of Full Transport Volume Demands of Straddle Monorail Vehicle of CRRC Changchun

1) Large Straddle Monorail

- Formation type: 4/6/8
- Passenger capacity: 962/1466/1970 persons
- Minimum radius of horizontal curve: 50m
- One-way hourly carrying capacity: 28,000~59,000 person-time/hour
- Train length (mm): 60200/89400/118600
- Acceleration: 1.0m/s^2
- Maximum operating speed: 80km/h
- Maximum gradient: 60‰

II. Introduction to Straddle Monorail Vehicle of CRRC Changchun

2. Realization of Full Transport Volume Demands of Straddle Monorail Vehicle of CRRC Changchun

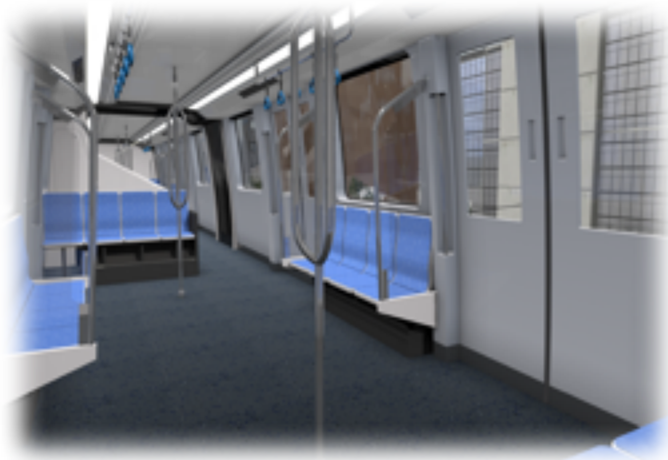
2) Small and Medium Straddle Monorail

- Formation type: 2/3/4
- Passenger capacity: 386/589/792 persons
- Minimum radius of horizontal curve: 50m
- One-way hourly carrying capacity: 11,000~23,000 person-time/hour
- Train length (mm): 27300/40000/52700
- Acceleration: 1.0m/s^2
- Maximum operating speed: 80km/h
- Maximum gradient: 60‰

II. Introduction to Straddle Monorail Vehicle of CRRC Changchun

2. Realization of Full Transport Volume Demands of Straddle Monorail Vehicle of CRRC Changchun

3) Small Straddle Monorail



- Formation type: 2/3/4
- Passenger capacity: 270/411/522 persons
- Minimum radius of horizontal curve: 50m
- One-way hourly carrying capacity: 8,000~16,000 person-time/hour
- Train length (mm) : 24360/35180/46000
- Acceleration: 1.0m/s^2
- Maximum operating speed: 80km/h
- Maximum gradient: 60‰

CRRC

II. Introduction to Straddle Monorail Vehicle of CRRC Changchun

2. Realization of Full Transport Volume Demands of Straddle Monorail Vehicle of CRRC Changchun

- **Comparison of Straddle Monorail Models**

	Large	Small and Medium	Small
Width of track beam (mm)	850	850/690	850/690
Vehicle dimensions (mm)	Length: Mc15500/M14600 Width: 2980 Height: 5300	Length: Mc13650/M12700 Width: 3093 Height: 5300	Length: Mc12180/M10820 Width: 2980 Height: 4412/4462
Height from rail surface to floor (mm)	1130	1130	700/450
Number of axles	4	4	2
Empty weight (ton)	≤27	≤20	≤16
Marshaling (number of cars)	4/6/8	2/3/4	2/3/4
Passenger capacity (person)	962/1466/1970 persons	386/589/792 persons	270/411/522 persons
Carrying capacity (person/hour)	28860/43980/59100 persons	11580/17670/23760 persons	8100/12330/16560 persons
Application	Branch lines and connections of first-tier cities; trunk lines of second-tier cities.	Trunk lines, branch lines or connections of second- and third-tier cities; tourist lines in scenic areas.	Tourist lines in scenic areas; trunk lines, branch lines or connections of third-tier cities.
Optional configuration	Unmanned driving, emergency traction, automatic reconnection, high-voltage direct-feed variable-frequency air conditioning, and DC750V/3000V power supply system.		

II. Introduction to Straddle Monorail Vehicle of CRRC Changchun

3. Technical Features of Straddle Monorail Vehicle of CRRC

On the basis of keeping the proven technology of the first generation and second generation monorail together with ten years of large transport volume operation experience and learning from technical advantages of monorail at home and abroad, CRRC Changchun develops the new straddle monorail vehicle with the latest urban rail transit technology.

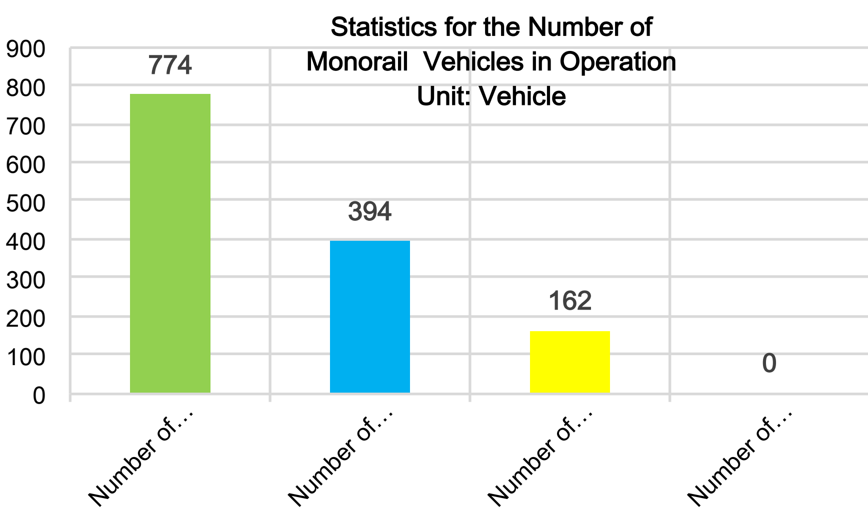
III. Introduction to Straddle Monorail Vehicle of CRRC Changchun

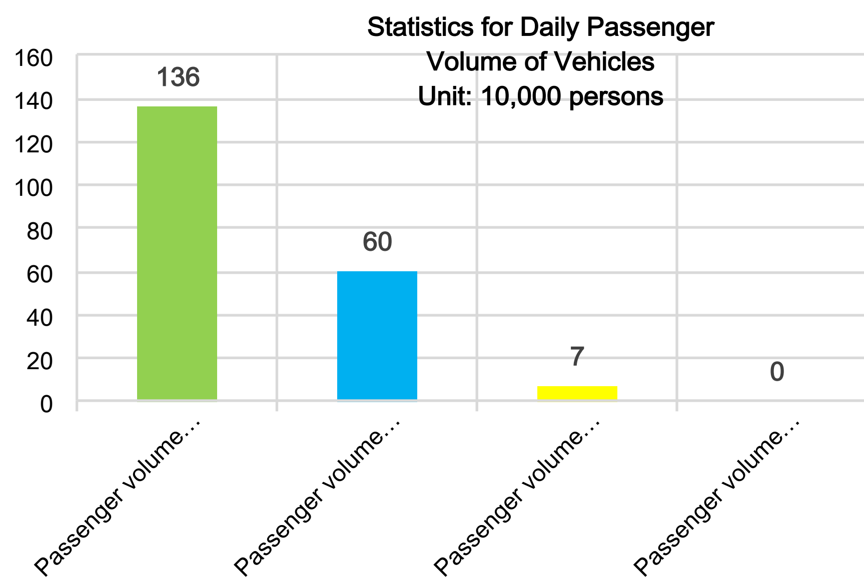
3. Technical Features of Straddle Monorail Vehicle of CRRC

- **Proven technology and rich performance**

With safe and stable operation, the vehicle technology platform has passed the operation test of large passenger flow in China;

The vehicle technology platform has the longest vehicle operation mileage opened to traffic and the largest number of in-operation vehicles in the world.



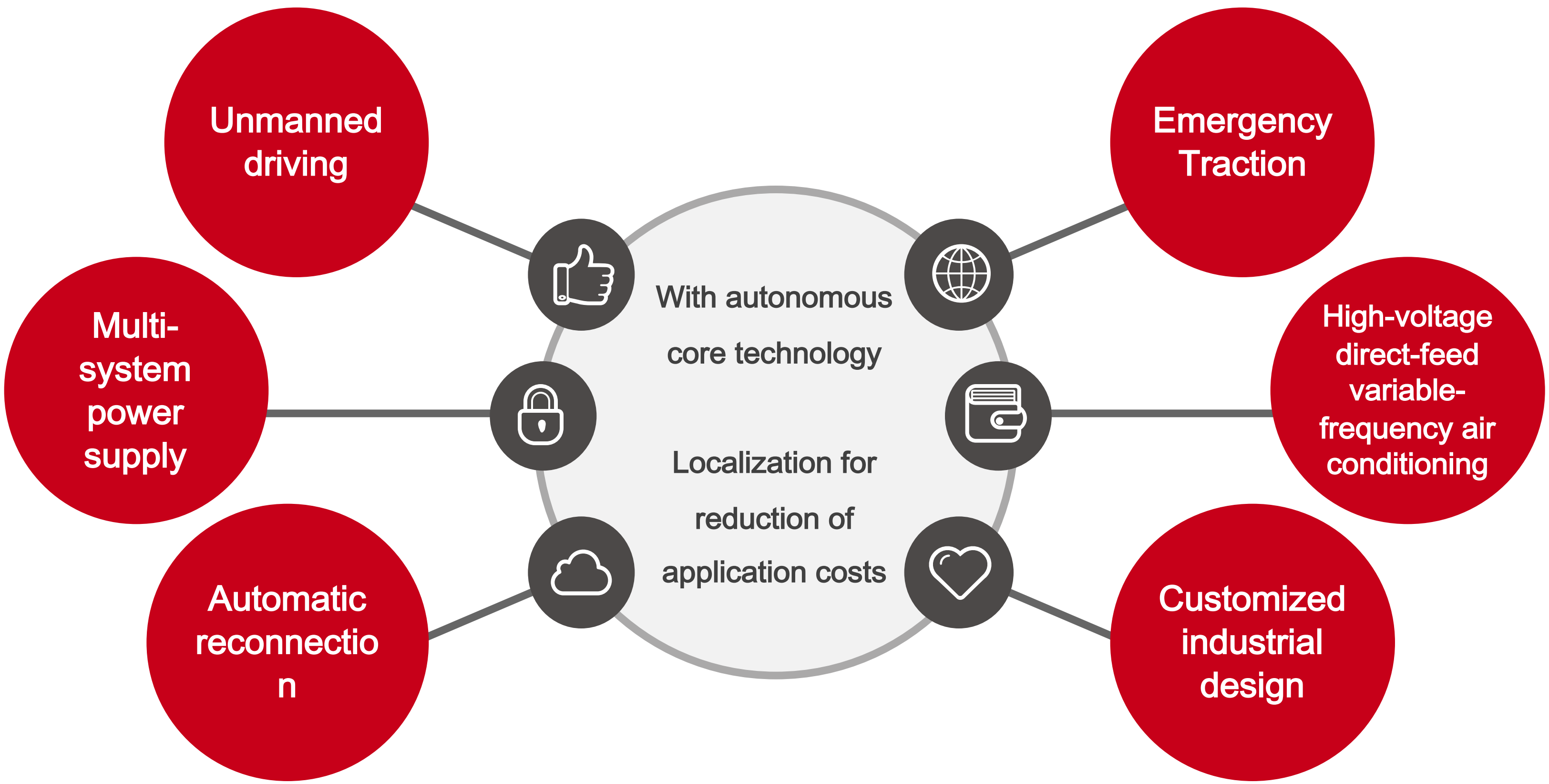


CRRC

II. Introduction to Straddle Monorail Vehicle of CRRC Changchun

3. Technical Features of Straddle Monorail Vehicle of CRRC

- Personalized and customizable



II. Introduction to Straddle Monorail Vehicle of CRRC Changchun

3. Technical Features of Straddle Monorail Vehicle of CRRC

- **Modern and Stylish Art Design**

Modern shape design that keeps pace with the trend of the times

People-oriented, stylish and modern interior effects control

CRRC

II. Introduction to Straddle Monorail Vehicle of CRRC Changchun

3. Technical Features of Straddle Monorail Vehicle of CRRC

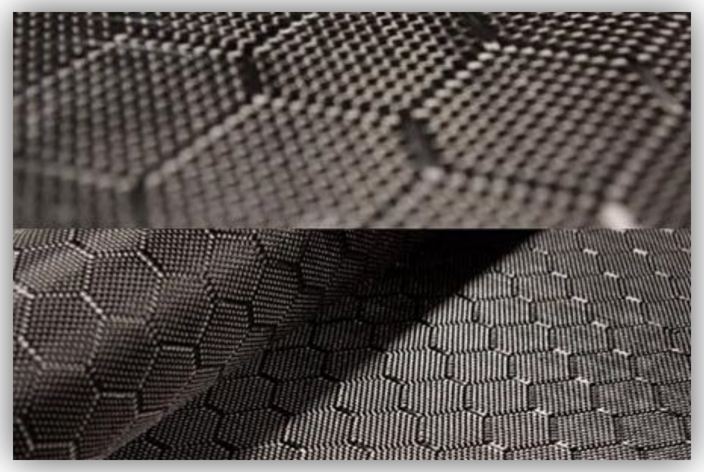
- **Energy saving and environmental protection**

Strict control of hazardous substances;

Adopt green material;

Environmentally friendly coating;

Lightweight, energy-saving and consumption reduction.



II. Introduction to Straddle Monorail Vehicle of CRRC Changchun

3. Technical Features of Straddle Monorail Vehicle of CRRC

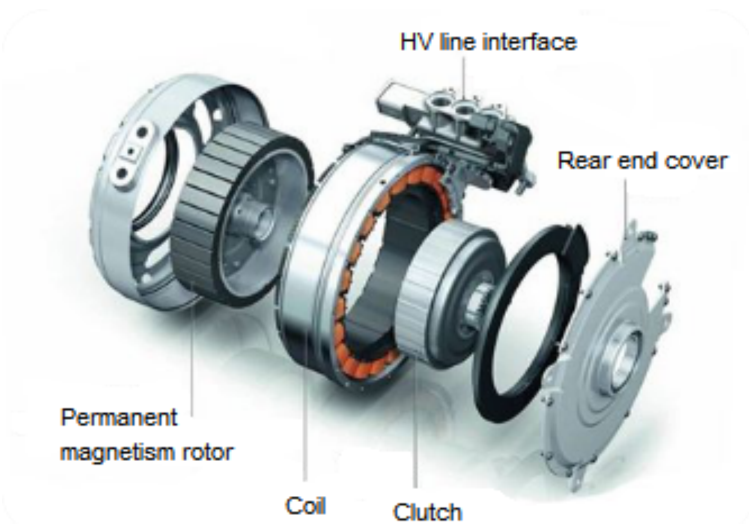
- **New Technologies and New Materials**

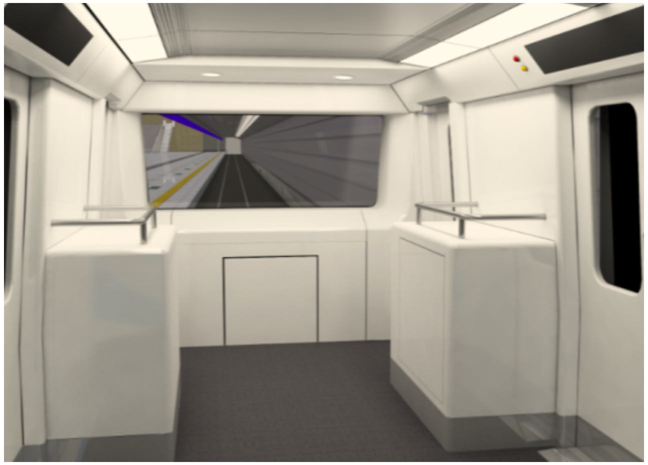
Permanent magnet motor technology;

Application of carbon fibercomposite;

Proven unmanned driving technology;

Automatic fault diagnosis and intelligent operation and maintenance.





II. Introduction to Straddle Monorail Vehicle of CRRC Changchun

3. Technical Features of Straddle Monorail Vehicle of CRRC

- **Strong environment applicability**

Vehicle: -40℃~+50℃ all-weather adaptation;

Device configuration adapts to snowy and freezing environment.

II. Introduction to Straddle Monorail Vehicle of CRRC Changchun

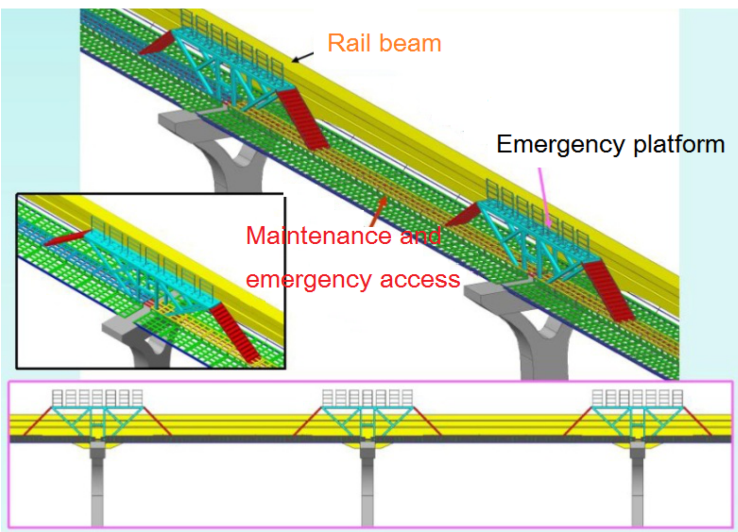
3. Technical Features of Straddle Monorail Vehicle of CRRC

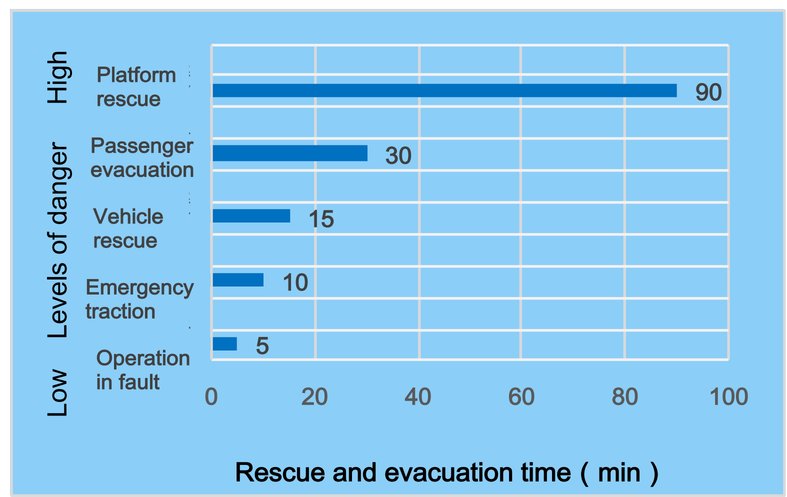
- **Safety Assurance**

Dual backup fault rapid processing;

Emergency traction emergency route disposition;

Several rescue and emergency evacuation plans.





III. Solutions

As the first domestic vehicle manufacturer to carry out research and development of the Straddle monorail, CRRC Changchun Railway Vehicles Co., Ltd. has successfully produced the first Straddle monorail train in China, and possesses a strong technical reserve.

The monorail vehicle platform of CRRC Changchun Railway Vehicles Co., Ltd. is of proven technology and rich performance and can provide different solutions to users according to city characteristics, transport capacity demand and actual environment and we look forward to your choice.


Thanks!

APPENDIX – B.4 HITACHI MONORAIL MARKETING

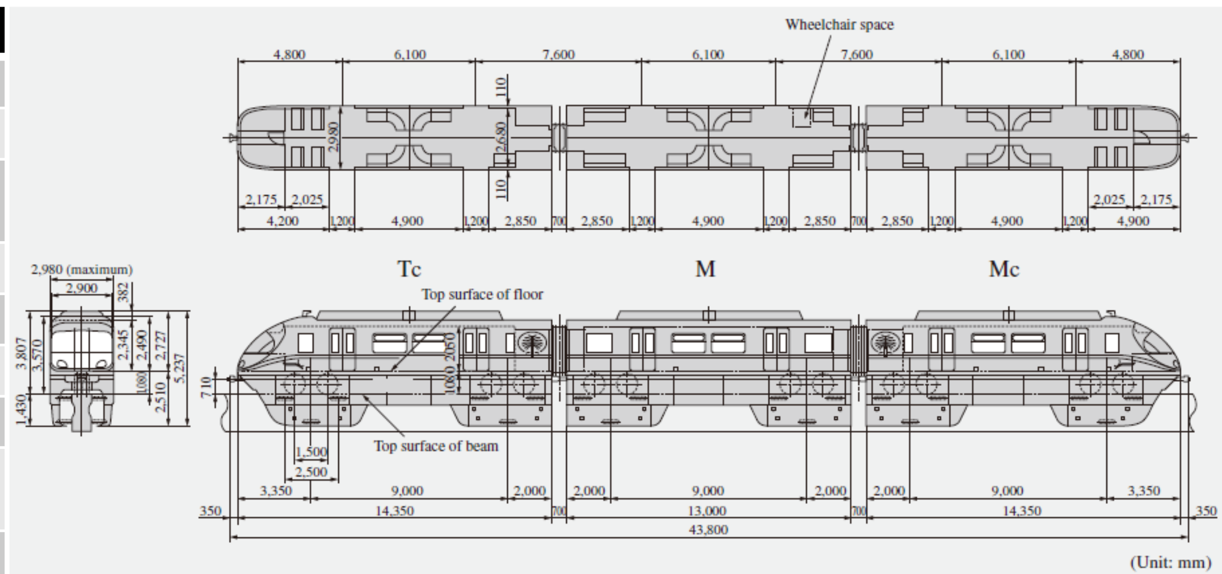
Palm Jumeirah Monorail, Dubai, UAE

HITACHI
Inspire the Next

Hitachi Monorail vehicles are available in small, middle and large sizes, each of which has different dimensions and axle loads

The monorail line (5.4km) connects the Palm Jumeirah to the mainland. The line opened on April 30, 2009 and is the first monorail in the Middle est

Item	Description
Vehicle type	Straddled Monorail
Trainset config.	3-car (Tc-M-Mc)
Passenger capacity	Tc and Mc: 98 M 106
Power feeding	DC 1500 V
Track beam width	800mm
Axle load	10t
Acceleration	1.0m/s2
Decelaration	1.11 m/s2 in normal operation 1,25 m/s2 in emergency
Maximum speed	70 km/h
Dimensions	Total lenght:43.8 m Width: 2.9 m
Operation	ATO driverless with attendant

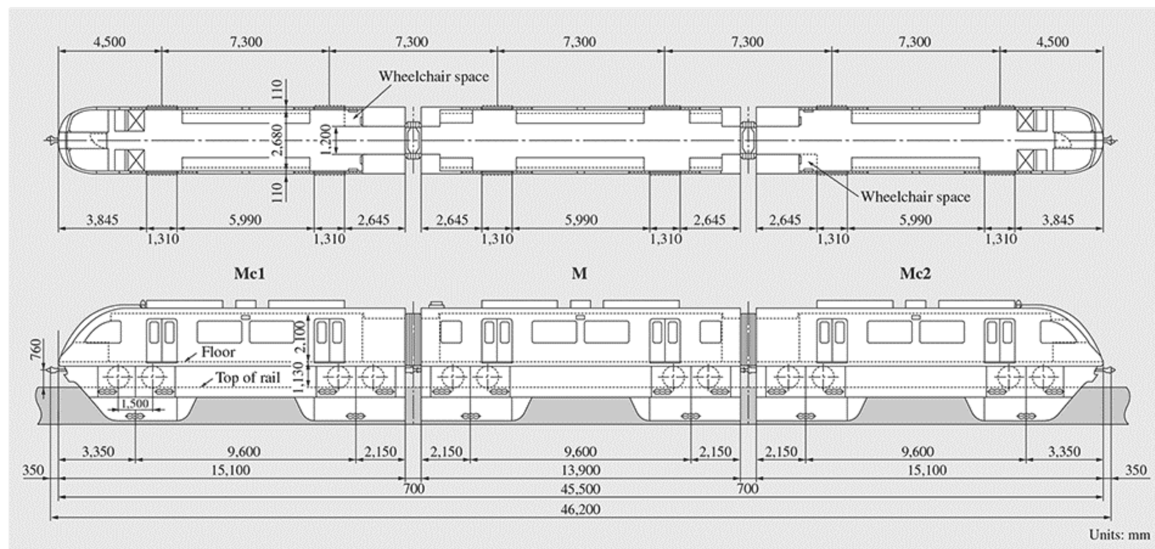


Daegu Metro Line No.3 Monorail, Korea

HITACHI
Inspire the Next

The Daegu Line 3line (24km) was opened in 2015 and is Korea's first straddle-type monorail Daegu Metro. Hitachi was contracted for the supply of monorail, track switches and signalling system.

Item	Description
Vehicle type	Straddled Monorail
Trainset Configuration	3-car (Mc1-M-Mc2)
Passenger capacity	265 (Mc1:84 Mc2: 84 M:97)
Power feeding sys.	DC1500 V
Track beam width	850mm
Axle load	11 t
Acceleration	1.0m/s2
Decelaration	1.11 m/s2 in normal operation 1,25 m/s2 in emergency
Maximum speed	70 km/h
Dimensions	Total lenght:43.8 m Width: 2.9 m
Operation	ATO driverless with attendant



Sentosa Express

HITACHI
Inspire the Next

Sentosa Express line (2.1km) was opened in 2007 and is connecting Sentosa Island to Harbourfornt on the Singapore mainland across the waters (4 stations: Vivocity, Resort World, Imbiah, Beach)

The straddle-type small monorail system was developed by Hitachi in Japan as a small, standard and cost-effective solution to the transportation needs of small to medium-sized cities. Some other features of the straddle-typed small monorail include being small in size, light and producing low noise levels; the capability of a greater passenger carrying capacity; a slim guide way structure as well as lower construction costs.

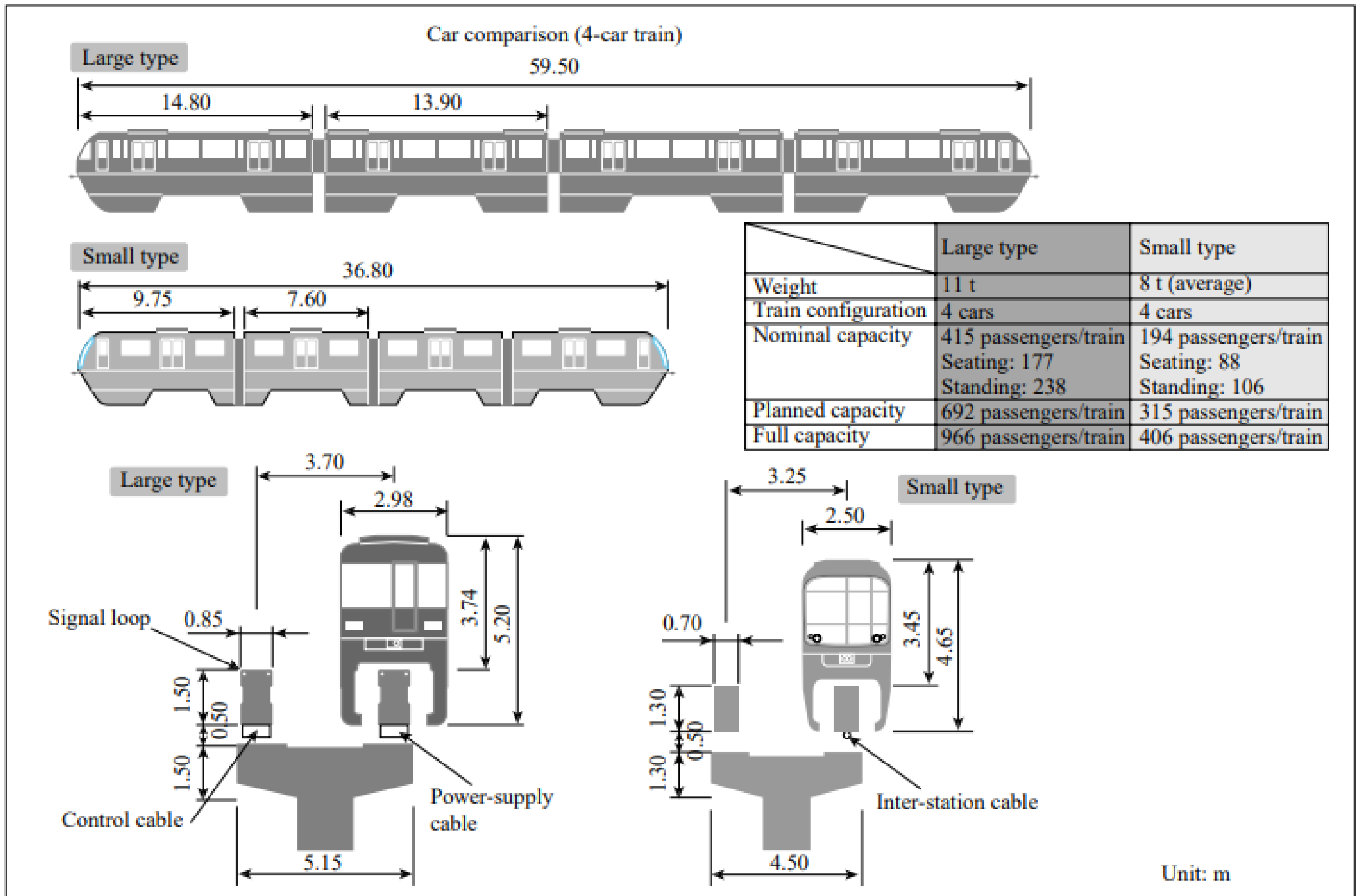
Since November 2017 Hitachi's Moving-block Wireless CBTC is in operation. The new system also includes an Automatic Train Operation (ATO) function, allowing the trains to be fully automated.

Item	Description
Vehicle type	Straddled Monorail
Trainset Configuration	2-car (Mc1-Tc)
Passenger capacity	184 (32 seated 152 standing)
Power feeding sys.	DC1500 V
Maximum speed	80 km/h
Dimensions	Total lenght:25 m Width: 2.7 m
Operation	Hitachi Moving Block Wireless CBTC ATC with Subsystem of ATO GOA 3 (DTO)

Kita-Kyushu Monorail, Japan

HITACHI
Inspire the Next

The Kitakyushu Monorail system is operating on the Kokura Line in the city of Kitakyushu in Fukuoka Prefecture, Japan, and is operated by Kitakyushu Urban Monorail Co. The line (8.8 km) connects Kokura station and Kikugaoka station, it was opened on January 9, 1985, on April 1, 1998



	Large type	Small type
Weight	11 t	8 t (average)
Train configuration	4 cars	4 cars
Nominal capacity	415 passengers/train Seating: 177 Standing: 238	194 passengers/train Seating: 88 Standing: 106
Planned capacity	692 passengers/train	315 passengers/train
Full capacity	966 passengers/train	406 passengers/train

APPENDIX C

FAREBOX RECOVERY AND OPERATING EXPENSE DATA OVERVIEW

Financial data including farebox data and operations and maintenance costs are difficult to obtain from private operators and from international systems (whether privately or government run). Therefore, a review of available data was conducted. The Federal Transit Administration's (FTA) National Transit Database (NTD) records the financial, operating and asset condition of transit systems. The NTD was set up to be the repository of data about the financial, operating and asset conditions of American transit systems. It is designed to support local, state and regional planning efforts and help governments and other decision-makers make multi-year comparisons and perform trend analyses.

In December 2019, FTA released its 2018 NTD data products, which provide the most recent data on transit ridership, expenses, fares, safety, assets, and other transit system information. Data is provided by Federal program recipients (required reporting) as well as from some voluntary reporters. The report presents summary data by transit mode and shows comparisons and trends between the modes. While some data is collected on monorail systems, those systems are not included in the main analyses in the report and are considered one of the "unique" modes due to the limited number of urbanized areas that operate them.

Six agencies reported 2018 data to NTD for in the category of monorail/automated systems including Seattle Center Monorail Transit, Morgantown Personal Rapid Transit, Miami-Dade Transit, Detroit Transportation Corporation, Jacksonville Transit Authority, and San Francisco. Las Vegas submitted information in 2017 but did not report 2018 data, therefore any numbers cited for Las Vegas are from 2017.

Due to the limited number of monorail systems with information it is hard to draw firm conclusions. Further, it is unclear what the numbers include. For example, operating expenses may range from daily operational costs to the full cost to maintain stations, access, maintenance facilities, etc. It is with those caveats that the following factors are presented.

The farebox recovery ratio is the proportion of total operating expenses covered by fare revenues. A farebox recovery ratio of 100% means that the fares collected cover the exact operating expense of the system. A ratio lower than 100% indicate that the fares do not cover operating expenses and a ratio higher than 100 % would indicate that the fares collected exceed the operating expenses. It is also important to note that transit agencies do not establish passenger fares simply based on the cost of each trip. None of the systems have farebox revenue that would cover the initial cost of construction. For the monorail/automated systems that provided data, some are either free or nominal ($0.75/trip) in cost resulting in farebox recovery ratios of 0 - 6.6%. Two systems are very successful, the Seattle Center Monorail and Las Vegas Monorail, with farebox recovery ratios of approximately 100%. Each are in urban areas with major attractions, are relatively short in length (approximately 1.0 and 3.9 miles) and have very high ridership carrying over 2.5-2.9 million riders annually. As a comparison, one of the most successful subway systems, the New York City Subway has a farebox recovery ratio of 73%. On average heavy rail (61.1%), commuter rail (50.7%), and commuter bus (47.9%) have the highest farebox recovery ratios. Vanpools are the highest at 73.6%.

Other financial metrics including service efficiency (operating expenses per vehicle revenue mile), service effectiveness (operating expenses per unlinked passenger trip) and operating expenses per passenger mile can be evaluated.

The average operating expenses per vehicle revenue mile for all the monorail/automated systems who reported ($22.62) is higher than the averages for bus ($11.15), heavy rail ($13.23), commuter rail ($18.30), BRT ($19.18), and light rail ($19.70). However, it should be noted that the two most successful systems from a farebox recovery standpoint, Seattle and Las Vegas, are below the average in this category ($20.57 and $10.73, respectively).

Operating expenses per unlinked passenger trip for all the monorail/automated systems who reported ($4.18) is lower than the average for light rail ($4.78), bus ($4.92) and commuter rail ($12.73) and is higher than the average for heavy rail ($2.44) and BRT ($3.53). Both Seattle ($2.13) and Las Vegas ($4.06) are below the average in that category.

Finally, operating expenses per passenger mile for all the monorail/automated systems who reported ($3.46) is higher than commuter rail ($0.51), heavy rail ($0.54), light rail ($0.92), bus and BRT ($1.31). And although Seattle and Las Vegas are lower than the average ($2.37 and $2.00, respectively), they are still higher than the other modes.

Source: https://www.transit.dot.gov/ntd