OVERVIEW OF MONORAIL RAPID TRANSIT SYSTEM

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***ABATRACT* - The history of Monorail is a fascinating story of innovation by governments, companies, entrepreneurs, transportation interest groups, researchers, and individuals. Today there are over 100 installations of various types and configurations throughout the world and many more are under construction or are being considered. Looking at the scenario of India, if the plans take off, India will become the monorail capital of the world. At present, 13 projects, covering between 300 and 350 km, at a cost of Rs 30,000-Rs 35,000 crore over the next 3-5 years, are in either the planning or implementation stage across the country. This paper looks at some of the events in the development of this new transit technology & discusses some of the important aspects regarding conditions favoring Monorail Rapid Transit, its implementation in urban areas & discussing how worthy is Monorail for Indian conditions.**

Keywords: **Monorail, LRT, Straddle Beam Monorail, CBTC System**

I. INTRODUCTION

When one looks back in history, one is overwhelmed by the terminology, acronyms, and technologies that have evolved over the years. As a starting point, it is probably appropriate to define a Monorail. "A single rail serving as a track for passenger or freight vehicles. In most cases rail is elevated, but monorails can also run at grade, below grade or in subway tunnels. Vehicles are either suspended from or straddle a narrow guideway. Monorail vehicles are wider than the guideway that supports them. Train sets should have a minimum passenger capacity of 40. PRT systems are excluded."

II. HIISTORY OF MONORAILS

The first monorail was made in Russia in 1820 by Ivan Elmanov. Attempts at creating monorail alternatives to conventional railways have been made since the early part of the 19th century. Around 1879 a "one-rail" system was proposed independently by Haddon and by Stringfellow, which used an inverted "/\" rail. The system was intended for military use, but was also seen to have civilian use as a "cheap railway." The first half of the 20th century saw many further proposed designs, that either never left the drawing board or remained as short lived prototypes. One of the first monorail systems planned in the United States was in New York City in the early 1930s. But the monorail was scrubbed instead for an elevated train system.

Some believe that the initial work on monorail began in the 1950s when General Motors was doing in-house research on automated highways and other companies were developing ideas on systems using driverless vehicles on separate guideways. In the late 1950s, the New York City Transit Authority experimented with automated operation for rapid transit in a project called the "Shuttle Automatic Motorman" (SAM). The system operated for about two years in the early 1960s on the 42nd Shuttle between Times Square and Grand Central Terminal.

In 1958, Alan Hewes of Cape May, New Jersey formed Universal Design Limited to develop a straddle beam monorail. His system was installed in ten amusement parks, fairgrounds, and zoos before being acquired by the Westinghouse Air Brake Company (WABCO). In the late 1960s, WABCO engineers developed a fully automated version which was installed at the Houston Airport in 1972.

During this same period, Charles Paine formed the American Crane Hoist Company and one of the objectives of his company was to develop a suspended monorail system for the Los Angeles Fairgrounds in 1962 and the 1964-65 New York World's Fair. Out of his experience came the

Braniff Airlines' Jetrail system. It was a fully automated suspended monorail system at Dallas Love Field Airport that connected a remote parking lot with the terminal building.

Meanwhile across the Atlantic, Habegger Limited, a small family owned Swiss firm was independently developing a "straddle beam monorail" for the 1964 Swiss National Exhibition in Lausanne. Numerous applications followed around the world and the system was first automated for Expo'67 – the world exposition in Montreal, Canada. The design proven durable and popular and was the genesis of monorails that are now offered by several companies.

These pioneering efforts initiated by small entrepreneurial firms were all low-speed systems marketed primarily for special purpose applications at expositions, fairgrounds, and zoos. Early attempts to use these simple system technologies for serious urban transit application were unsuccessful. The story might have ended had not the U.S. federal government got involved. The U.S. government began supporting monorails by providing a grant to Westinghouse in the early 1960s to assist in the construction of a test facility in South Park, near Pittsburgh, for a system known as "Sky bus" or "Transit Expressway". The system featured the first automated rubber-tired vehicles capable of operation at 60-second headways. The vehicles had a capacity of approximately 100 passengers and a top speed of 80 km/hr.

III. OVERVIEW OF SOME MONORAIL PROJECTS

A. Chongqing Monorail

China's first ALWEG-type monorail system officially opened on June 18, 2005 in Chongqing, China. The monorail serves the main business and public districts. Line 1 begins as a subway under downtown Chongqing, then runs west elevated along the southern bank of the Jialing River, then turns south into the city's southwestern suburbs, ending in the Dadukou district. Construction began in January of 2001, and the initial line includes 2.2-km of subway tunnel with three subway stations. The Japanese Bank for International Cooperation (JBIC) provided a loan to finance the development of the monorail. The Chongqing Monorail is capable of carrying 30,000 passengers per hour at peak hours. In September of 2011 Line 3 opened, adding over 17 kilometers to the system and making it the longest monorail system in the world, surpassing the previous record holder in Osaka, Japan. Then in December of 2011, Line 3's extension to Jiangbei Airport opened. With that addition, Line 3 became the longest monorail line in the world at 39.1 kilometers. In December of 2012 Line 3 opened an extension in the Yodong district, making the line even longer at over 55 kilometers with 39 stations. Line 2 and 3 were connected in the south, which will likely keep Chongqing Monorail as the largest time for a long time. The Chongqing Monorail also is the only monorail system in the world with an X-shaped crossover point. Line 3 features the highest river crossing of any monorail system in the world, with the Jialing River crossing on the Chongqing Yu'ao Jialingjiang Bridge.

TABLE I. SALIENT FEATURES OF CHONGQING MONORAIL

Chongqing Monorail	
Type	Straddle beam Monorail
Number of lines	4
Number of Stations	77
Daily Ridership	7,00,000
Annual Ridership	4,50,00,000 (Line 2 only)
Begun Operation	2005
Overall System Length	104.2 kms

Source: The Monorail Society

B. Kozhikode Monorail

Kozhikode the traditional capital of Northern Kerala and the most important city of Malabar region of Kerala is the third biggest Municipal Corporation in Kerala. Kozhikode is fast emerging as a prominent educational, commercial and trade Centre having well established national/international trade routes. Kozhikode city alone accounts for 40% of the urban population in the District and is experiencing a rapid growth in urbanization. Like any other urban areas, it is also having a steady growth of vehicle population and travel demand of people has been increasing tremendously. In order to improve the traffic situation, efforts were made to improve the road infrastructure. Unfortunately, such improvements are note able to cop up with the increasing demand.

TABLE II. SIZE OF THE COACH OF KOZHIKODE MONORAIL

Size Of The Coach			
Particular	**Length**	**Width**	**Height**
Leading Car	Upto 16m	Upto 3.15m	Upto 4.05m
Intermediate Car	Upto 15m	Upto 3.15m	Upto 4.05m

Source: NATPAC

Passenger Carrying capacity

- Passenger carrying capacity (@ 6 persons per square meter of standee area) for 3 – car train set (indicative) will be approx. in the range of 400 to 525.

- Passenger carrying capacity (@ 8 persons per square meter of standee area) for 3 – car train set (indicative) will be approx. in the range of 500 to 675.

The most advanced Communication Based Train Control (CBTC) system, generally conforming to IEE 1474 and ATS (Automatic Train Supervision) has been proposed for Kozhikode Monorail Project.

TABLE III. FARE STRUCTURE OF KOZHIKODE MONORAIL

Fare Structure	
Distance in	**Fare in 2015-16**
0-2	6.00
2-4	10.00
4-6	12.00
6-9	15.00
9-12	18.00
12-15	22.00

Source: NATPAC

TABLE IV. PROJECTED TRAFFIC/DAY

Projected Traffic Per Day	
Year	**Lakhs/day**
2015-16	1.48
2021-22	1.77
2031-32	2.37
2041-42	3.19

Source: NATPAC

The proposed Mono Rail project will yield benefits due to equivalent reduction in road traffic and certain socio – economic benefits. Tangible benefits are due to reduction in fuel consumption (Vehicle operating cost – VoC) of vehicles and travel time of passengers. Non tangible benefits include reduction in accidents, pollution and maintenance costs due to the monorail project.

C. Tokyo Monorail

The monorail has operated without flaw since 1964 when it opened in time for the Olympics of that year. It carries people from the Haneda airport to Hamamatsu Cho Station, which is located on Tokyo's main rail loop. It is a dual rail line in which trains reverse direction each end via switches creating a proof of sound technology.

As of 1997, over 1 Billion passengers had ridden the Tokyo-Haneda Monorail. It possesses the record of the World's busiest Monorail line.

The Tokyo-Haneda line proves that monorail can be built almost anywhere. The tracks begin by paralleling the Shinkansen and city main rail lines. They then cut through heavily developed business and residence areas. Much of the supports are in the canals between the many artificial islands of Tokyo Harbor. At one point, there is a subway segment that runs beneath one of the canals. Stations are built inside buildings, at ground level and in subways beneath Haneda Airport terminals. An extension opened in 2004, with the addition of Terminal Two Station at Haneda Airport. In 2010, a new station opened for Hamada's new International Terminal. Pictured are a Type 1000 train, which was introduced in 1990, and a Type 2000 train introduced in 1997 (photo by Hiroshi Naito). It is the best example of Monorails' adaptability to Surrounding Environment.

TABLE V. SALIENT FEATURES OF TOKYO MONORAIL

Tokyo Monorail	
Transit Type	Straddle Beam Monorail
Number of lines	1
Number of stations	11
Daily Ridership	3,00,000
System Length	17.8km
Begun Operation	September 17, 1964
Operator	Tokyo Monorail Co. Ltd

Source: The Monorail Society

D. Mumbai Monorail Project

Considering the increase in population, increased travel demand and narrow road networks running through congested structures, there is a need of a system which will occupy less space as well as reduce travel time. With the objective, to support public rapid transit system such as suburban rail system and metro rail system and where public rapid transit system is not available or impossible to provide such system and where widening of roads is not possible due to structures on either sides, Mono Rail system is proposed to be implemented by MMRDA/GOM.

TABLE VI. PROJECTED TRAFFIC PER DAY

Projected Traffic Per Day	
Year	**Lakhs/day**
2016	1.25 (7400 pphpd)
2031	3.00 (8300 pphpd)

Source: MMRDA

TABLE VII. SALIENT FEATURES OF THE MUMBAI MONORAIL CORRIDOR

Salient features of the corridor	
Design headway	3 minutes
No. of Stations	18 nos.
Height	Around 11.5 m above Ground Level
Train Composition	4 cars
Train Capacity (4 cars)	568 Max.
Design Speed	80 kmph
Scheduled Speed	31 kmph
Operation Hours	0500 Hrs.- 2400 Hrs.
Curves	9 kms (93 curves in 20

	kms)
Design Life	120 years
Horizontal Curve Radius Main Line	100 m(Nominal) & 50 m(Minimum)
Alignment	94% on Gradient
Safety	As per NFTA 120

Source: MMRDA

IV. MONORAIL & METRO RAIL: COMPETITIORS OR COMPLIMENTARY

Monorail is a suitable system for urban transportation. There are many opportunities for us to introduce monorail systems the world over; not just in India, but also in China, South-east Asian countries, etc...

India, with its congested cities, where alignment of metro routes is not always possible, monorail is the most obvious alternative. Today, Nine Indian cities have a population of more than 5 million and, by 2051, more than 35 cities will reach that figure. To cater to such a large urban population, India needs a comprehensive, sustainable and integrated rail transportation system.

With 40 per cent of India's population set to live in urban areas, there will be a need for extensive transportation infrastructure: more metro and railway lines, roads, sidewalks, foot overbridged and cycle tracks. "It is not possible to acquire large tracts of land by displacing people in thickly populated areas for a mass rapid transportation system such as the metro. One practical solution is to create connectivity to existing suburban railheads with monorail, which requires less space,"

Looking at all aspects it can be said that, Metros and Monorail are complimentary to each other and one is not a substitute for the other; each has its own advantages and disadvantages.

TABLE VIII. COMPARISON OF MONORAIL OVER METRORAIL

Comparison		
	Metrorail	**Monorail**
Cost/Km	175 crore	125 crore
Speed	80-120 kmph	30-90 kmph
Passenger Capacity/hr.	40,000	20,000
Fare Structure	8-30 Rs.	6-22 Rs.

*Delhi Metro, # Kozhikode Monorail

A monorail is usually confused with cable car, light rail or tramways. A monorail, in simple terms, is an electric-powered bus that runs on an elevated concrete beam. The capacity of a Metro system, which can accommodate up to nine cars, is about three to four times more. Thus, the capacity-to-cost ratio is better for a Metro system, even though the per kilometer construction cost is more.

We can say that, for cities that have a population of less than three million, monorail is the ideal mode of transport. For denser cities, monorail can ideally serve as the feeder line that brings passengers in and takes them out of the Metro network.

Monorails can be built very quickly and can extend into outer areas Monorail is ideal for building a regional network. But within the city, the system will reach its capacity very fast."

A sustainable urbanization strategy must involve dispersal of the population away from the city core and the dream of extending mass rapid systems such as suburban rail and Metro Rail into outer areas is just not economical. "Revenue from mass rapid systems can meet only recurring cost. The capital cost has to be written off. Monorail is much better when you are looking at a solution not just for the city, but also its rapidly expanding suburbs."

Monorail follows the lines of green transportation, as its coaches move on rubber tyres on concrete beams, creating less noise and vibration during operation, and is powered by electric motors which are silent, efficient and clean. In Mumbai Monorail, It is estimated to save approximately 200 tons of CO2 a day. The four-car trains will carry 568 passengers each, with a capacity for expansion in the future by adding additional rakes. It will augment local railway services and will offer faster connectivity.

V CHARACTERISTICS OF MONORAIL SYSTEM

From past projects & their level of service we can analyze some characteristics for Monorail Rapid Transit. These characteristics provide guidelines of suitable conditions for monorail. If the Monorail will be planned with keeping in mind these considerations, it will surely provide optimum serviceability.

TABLE XV. CONDITIONS FAVORING MONORAIL RAPID TRANSIT

Conditions favoring Monorail Rapid Transit		
Characteristic	**Recommended Value/**	**Justification**

	Features	
Length	6.5 to 50 kms	At lower values, time savings from ROW A travel becomes appreciable and elevated stations become practical despite cost. At upper values, monorail cannot compete with the faster speed of heavy rail, and cheap land for at-grade ROW A becomes increasingly common.
Distance Between Stations	0.5 to 3.5 kms	
Capacity (8 standees/sq meter)	5,000 to 25,000 pphpd	At lower value, monorail investment costs become justified. At upper value, monorail train & station bulk become system liabilities and advantages from automation (operating cost, quality of service) become negligible.
Population/ Employment Density	Low-Medium to Medium-High	Elevated transportation can be problematic in areas with single-family home densities due to privacy concerns. Extremely high densities may make accommodating space needed for monorail and monorail stations challenging.
City Age/Image	Modern	Monorails' aesthetics are less questionable in modern cities, or in areas with modern architecture.
Geological/Environmental conditions	The more difficult and problematic, generally the greater Monorail's advantage over conventional rail.	Monorail can be a cost-effective alternative to tunneling; aerials act as mini-bridges over sensitive spots and monorail structures have a small footprint.

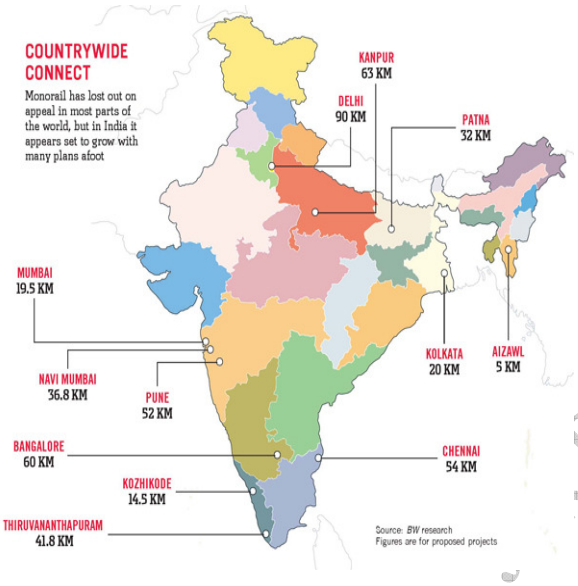
Monorail is best suitable for 6 to 50 kms. It means that for small distance it can serve in optimally because we can provide stations at distance from 0.5 to 3.5 kms which is at present best suits to urban conditions of India.

For, Tier II cities of India like Kozhikode, Vadodara, Madurai, Tiruchi, Koimbatore, etc. Monorail would be cost effective & a perfect option. Kozhikode is the best example for that. However it can also serve Metro cities. Monorail can serve as linking the sub urban area to CBDs. Chongqing Monorail is the best example of Monorail implementation in Metro city. The population of the Chongqing is around 2.5 crore.

Line direction capacity should be 5000 to 20000 with 6 or 8 standees/ sq. meter. Generally, every city needs some landscaping in it. In that case Monorails' aesthetics are less questionable because they are integral part of modern architecture.

The more difficult and problematic the Geological or Environmental conditions are, generally the greater Monorail's advantage over conventional rail. It can be a cost-effective alternative to tunneling; aerials act as mini- bridges over sensitive spots and monorail structures have a small footprint which saves a precious urban space.

VI. INDIAN SCENARIO



If the plans take off, India will become the monorail capital of the world. At present, 13 projects, covering between 300 and 350 km, at a cost of Rs 30,000-Rs 35,000 crore over the next 3-5 years, are in either the planning or implementation stage across the country. With regard to the urban transport system in India, there is a growing emphasis on effective use of demand as well as supply-side management measures of the same. Individual cities and towns cannot focus towards catering only to personal means of transportation, as it would over a period of time; prove to be a bottleneck in the infrastructure growth of any city. As we talk about improvising and promoting public transport, it is also important to understand that it requires both an increase in quantity as well as quality of public transport. Therefore, the best suited approach to increase the efficiency of urban transportation system in India would be to integrate the various modes of public transport seamlessly, including intermediate public transport.

VII. CONCLUSION

From an engineering point of view the basic characteristics of a straddle monorail's guideway and support has undergone little drastic change over a 40 year period. Computer aided design, and improvements in concrete constructions have helped somewhat. Much more significant is the appreciable amount of attention that has been paid to mapping out the tradeoffs involved with monorail aerials that will undoubtedly make this transit mode much more competitive.

Likewise, while monorail vehicles have benefited from modern transit technology, and are built to standards comparable to heavy and light rail vehicles, progress in design have been as impressive as improved technical standards.

Monorail technology is well suited to urban transit applications. It compares favorably to traditional rail technology on the whole. While monorails do have several significant disadvantages that cannot be outright dismissed—like somewhat higher energy costs (for rubber-tired systems) and slower switching as compared with similar rail systems, it is rare that these considerations would amount to a "fatal-flaw". In fact, these considerations should, more often than not, be minor in the general exercise of mass-transit planning. Indeed, it is in those very areas where monorail technology holds the advantage over steel-rail technology— most notably in its lower noise production and greater grade-climbing abilities—where monorail has the ability to make a fixed transit line feasible where it would not be otherwise.

With improvement in technology and higher passenger capacity options, the cost of construction of a monorail network has come down and as well as the quality of service has grown very high.

Monorail is best suitable for Indian tier II cities where the cities have minimum urban space and population around 5 million. And for Metro cities, an integration of Metrorail & Monorail should be preferred for optimum performance. The best example of this integration is Chongqing. It has 107 kms overall system length. It consisting of 56 kms of Monorail & remaining Metrorail. Indian cities are facing the same problem as the cities in China are facing. The problem is to move large numbers of people in less time with using minimum urban space. So for that, it can be said that monorail can be part of the solution for the Indian urban cities.

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