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BULLET TRAINS

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NATIONAL BOOK TRUST, INDIA

First published in 2016 (*Saka* 1938)
by the Director, National Book Trust, India
Nehru Bhawan, 5 Institutional Area, Phase-II
Vasant Kunj, New Delhi-110070
Website: www.nbtindia.gov.in

Bengaluru • Kolkata • Mumbai
Chennai • Guwahati • Hyderabad
Agartala • Patna • Cuttack • Kochi

ISBN 978-81-237-7974-4

₹ 150.00

Lasertypeset by Capital Creations, New Delhi and
printed at J.J. Offset Printers, Noida

Introduction

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Preface

“Speed, it seems to me, provides the one genuinely modern pleasure.”

- Aldous Huxley

The big shiny trains running at break-neck speed popularly called as bullet trains provides genuine pleasure to millions of happy commuters. The journey of high speed travel has been very interesting. Initially the carriages were pulled by human beings, followed by horses, fixed engines and steam locomotives. When the steam locomotive Rocket touched the speed of 20-30 miles per hour during Rainhill trials in 1829 it was considered revolutionary. The advent of electric traction challenged the prevailing notions and the increase in population and economic activity necessitated better connectivity. Japan took the lead and the first modern bullet train started in Japan in the year 1964. France and China followed suit and today Bullet trains run in 15 countries. There is great deal of interest in bullet trains. We must keep abreast of this latest technological wonder knocking at the door of India. The amount of interest the bullet trains have generated worldwide make it a fit case to read a book on Bullet Train.

Mere reading of isolate articles on bullet trains will not make any one wiser. It will require a concise and comprehensive study material dealing with all the nuances of the subject. There is no book available to cater to this need. Now someone will say is there any need? Or I am just trying to generate the need. Dispassionate thinking will make it clear that no big infrastructure project can be a success unless it has the support of public. But how will the public support? The issue of support comes only when they understand the subject. It is necessary to generate awareness about bullet trains not only among masses but also among transport professionals and all those who are engaged or likely to be engaged with such projects.

The idea of the book came out of the feeling to make the young minds aware about the latest technological wonder and also contribute in a humble manner for the success of bullet train project. This book is an attempt to generate mass awareness about bullet train projects and also to develop the human resources for these projects. In doing so, the book looks at a gamut of issues including its technology, economics, environment through analysis based on experiences of such projects worldwide.

This book has been written after considerable research and wider consultation. Reading of this book will make one understand the background and current status of bullet trains all over the world with special emphasis on India. Attempt has been made to bring out the detailed benefits of the project and at the same time the criticisms have also been analyzed. **Why the bullet trains have the nose? Can such trains run on existing railway track? How will driver observe the signal?** These are some of the questions that come to the mind when one thinks of bullet trains. It will be interesting to know how the **Owl feather and kingfisher dive** have helped in improving the speed of bullet trains. Chapter on Bullet train technology will answer all such questions.

Where is the money? **Can we afford such a project?** How to generate finance? All these issues are covered in great detail.

The implementation process has been explained and resources for further study have also been indicated.

How the **breaking of sound barrier by land vehicle** has led to further improvement in the speed of trains? And What Promises the **ET3 popularly called Space travel on earth hold?** Will it really be possible **to travel from Kashmir to Kanyakumari in around half an hour?** The book attempts to address all such queries.

The **bullet train terminology** is a unique feature of the book that will make the understanding of the concept very clear.

I also extend my appreciation to those who provided me with useful information and guidance especially Sh. Manoj Akhouri, Sh. Ved Prakash, Sh. Sharat Sharma, Sh. S K Sinha, Sh. Vikas Kumar, Sh. Govind Vallabh, Sh. A K Puthia, Sh. Omprakash, Sh. A. K Singh and many friends and colleagues. Help of Sh Amit Jain, Sh. Rishi, Sh. Akhilesh and Sh. Rajkumar Porov is also appreciated.

My wife Archana provided the much needed encouragement and support.The biggest appreciation is reserved for my kids Ayush Raj and Annika Priya as they constantly motivated me to write the book and also suggested the ways to make the book more attractive.

This book would not have been possible but for the blessings of the elders and almighty. Thank you one and all.

1

Introduction

> "I never travel without my diary. One should always have something sensational to read in the train."
>
> - Oscar Wilde

What do we mean by bullet trains? Bullet Trains may be loosely defined as the high speed trains running on a dedicated track with specialized rolling stock at a speed in excess of 250 km/h. The nose of high speed trains loosely resembles the shape of a bullet and due to their characteristic high speed, these trains are sometimes referred to as Bullet Trains, although the appropriate technical term for such trains is High Speed Trains.

Japan was the first country to build dedicated high speed rail lines. Initially the high speed project of Japan was named *dangan ressha* which literally means bullet train in English. The research for high speed trains had started way back in early 1900s in Germany when two rail cars achieved the speed of 206.7 km/h and 210.2 km/h. Lot of development has taken place since then.

At present Bullet Trains are operational in fifteen countries over a dedicated network of around 29000 km. Almost half of the dedicated high speed rail network is in China. Japan, Spain, and France are the other countries where the high speed rail network exceeds 2000 km. The other countries where high speed rail network exists are Austria, Belgium, France, Italy, The Netherlands, Switzerland, United Kingdom, Taiwan, South Korea, Turkey and USA. Apart from these countries high speed rail network has been planned in countries like Poland, Portugal, Russia, Morocco, Saudi Arabia, Brazil, Mexico and India.

Bullet Trains signify the high level of infrastructure development of a nation and thereby it is a very significant example of advancement. These whizzing wonders not only generate awe but also have significant environmental, social, political and economic benefits as well. Bullet Trains make the transportation system efficient, effective and sustainable.

Bullet Trains put comparatively less pressure on energy resources and ecosystem. These trains have been found to be the most energy efficient mode of transportation with the lowest carbon foot print. It is significant to point out that road traffic accounts for 73% of global transport emissions, while the aviation, shipping and rail sector accounts for 13, 9 and 2% of emissions respectively. When we decide to do the cost comparison of various modes of transport we must internalize the external costs. External costs relate to transport costs generated by transport users and not paid by them but by society as a whole such as congestion, air pollution, climate change, accidents, noise, landscape damage etc. Road Transport is responsible for most of this cost (93%), followed by air transport(5%) and rail transport with less than 2% of total external costs.

Bullet Train projects have very long gestation period and therefore its financing becomes a very important issue. Till now, all the high speed train projects were funded by the government but in future it may be done through Public Private Partnership (PPP) and other innovative methods like value capturing etc. Successful financing of these projects will depend on administrative efficiency, stable politico economic conditions, investment grade credit rating, corruption perception index, consumer payment discipline and enforcement, independent regulatory and judicial machinery etc. These factors must be taken care of to ensure a successful investment of bullet train projects.

Bullet Trains are among the most admired pieces of technology. They are manufactured as one contiguous driving units, passenger cars, power units etc., with driving cabs at either end giving them more stability. Articulated bogies are the standard norms of high speed trains. In this technology, the articulated cars share one bogie between two coaches for all coaches. These trains have highly aerodynamic designs accentuated by pointed front and back ends, similarly open connections on vestibules between coaches are eliminated. These trains are air sealed and pressurized inside. Generally made of aluminum alloys exteriors of these trains are highly polished. Almost everything on the bullet trains and its network is controlled by computers and sophisticated sensors on the trains and track ensure its safe operation. Bullet Trains when going around the curve at high speed tilt so that the passengers are not inconvenienced due to the centrifugal force generated by the curve. Tracks of bullet trains have no joints but are continuously welded and the curve design, points bridges and tunnels are specially designed to ensure smooth running of bullet trains. There are no line side signals as driver of a bullet train cannot see those signals at such high speed. Instead of line side signals cab signaling is adopted which communicates track status and related information to the driver.

These high speed trains, today, are successfully running in fifteen countries and are a definite showpiece of advancement. Then why should India remain behind? High speed in the field of transportation is a must to achieve greater mobility.

Imagine if the journey from Kashmir to Kanyakumari and from Dibrugarh to Dwarka becomes an overnight journey. What kind of cultural, economic, social and political integration it will achieve! Unity in diversity has been the hallmark of India. Lack of proper connectivity hampers the desired growth prospects but the bullet trains will help in bringing the much desired unity and India will truly emerge as global player. Going one step further, if we have bullet trains connecting important cities in South Asia like, Dhaka, Lahore and Nayphidaw, then the economic and cultural exchange will provide immense opportunities for the emergence of India as a global player.

To the uninitiated it may seem like a utopian dream. One may argue that we cannot afford investments of such scale, which is about 100-200 crore per kilometer. One should remember that all the cost estimates are based on current status of technology and our dependence on foreign countries. What if we are able to indigenize the technology? What if we are able to produce different signaling equipments, track material, rolling stock etc, in India? What if we have our own technical expertise? What if Public Private Partnership model becomes a grand success? What if other innovative financing methods become a success? All these are not mere dreams but are realistic ambitions.

Critics also point out that it is better to strengthen air transport if we want faster connectivity. There are many good reasons to choose high speed rail over air travel. The travel on bullet trains is generally cheaper than airfare moreover the bullet train fares are stable unlike the air fares which keeps changing frequently thus making it agonizing to choose the correct time for purchase of air tickets. Bullet train travel offers flexibility. World over most short trips do not require prior reservations, one can simply show up at the station to grab the ticket for the next train without worrying about the exorbitant last minute fares for air travel. One can carry more baggage in bullet trains and there is less hassle as there is no need to arrive hours early, wait in long security lines, ration one's liquid and gels as is the case with air travel. Unlike airports, most bullet train stations are located in the heart of the cities, so there is no need to take a long expensive cab ride to airport. Bullet Trains are more energy efficient per passenger kilometer than planes or cars.

Do we need Bullet trains in India? Yes, we do need as it offers immense environmental, social, political and economic advantages and will showcase our development to the world.

Where do we stand now? The high speed train project has gained momentum in recent times. Diamond quadrilateral project of high speed trains network has been envisaged. Indian Railways has identified nine corridors for high speed passenger trains to run at 160-200 Kmph.

The nine corridors are:

i)	Mumbai	-	Ahmedabad
ii)	Delhi	-	Agra
iii)	Delhi	-	Chandigarh
iv)	Delhi	-	Kanpur
v)	Nagpur	-	Bilaspur
vi)	Mysore	-	Bengaluru-Chennai
vii)	Mumbai	-	Goa
viii)	Chennai	-	Hyderabad
ix)	Nagpur	-	Secunderabad

In July 2014 Indian Railways conducted the trial run of Shatabdi Express upto a maximum speed of 160 Km/h between Delhi-Agra. The train completed the 200 Km distance in 90 minutes and the detailed examination of all the technical issues like track structure, bridge strength, signalling system, security, etc. was done. In August 2014 Indian Railways permitted foreign direct investment in high speed rail projects.

The Railway budget of 2014 highlighted the Golden Quadrilateral Rail Network linking the four Metro Cities and also mentioned that running semi-high speed trains with proper safety measures on select routes will be a matter of top priority for the government. A provision of Rs 100 Crore has been made in Rail

Budget for high speed project to Railway Vikas Nigam Limited. The High Speed Rail Corporation has been set up to conduct studies, design the parameters, develop financing models, project development, project execution, construction upgradation, manufacture, operation and maintenance of high speed rail system on existing as well as new rail corridors.

Among the steps that have been taken to implement the project include:

1. Necessary institutional framework in the form of High Speed Rail Corporation as a subsidiary of Rail Vikas Nigam Limited.
2. Identification of sections for the proposed high speed rail system.
3. Pre-feasibility studies are being done and techno economic investigations are also being carried out.
4. Right environment for investment has been created by allowing 100% foreign direct investment.
5. Fund has been allotted for the Ahmedabad Mumbai high speed rail corridor in rail budget of 2014.

It is hoped that the book would create an awareness among the general public on bullet trains.

2

Horse, Steam Engine and Shinkansen

History of Train Speed

When it came to speed, the friction force was a serious limiting factor for vehicles on road. It was observed that if vehicles move on a guided track, then friction is lesser and speed is higher. The earliest reference to such guided tracks is found in Greek history. **Diolokos** was a paved trackway near Corinth in Ancient Greece which enabled boats to be moved overland across the Isthmus of Corinth. The main function of the Diolokos was the transfer of goods, although in times of war it also became a preferred means of speeding up naval campaigns. The 6 km to 8.5 km long roadway was a rudimentary form of railway and operated from c. 600 BC until the middle of the 1st century AD. Diolkos in a way represented the seminal idea of a railway, in the basic sense of a prepared track which so guides the vehicles running on it that they cannot leave the track.

The next significant development was the wagonway. **Wagonways** consisted of the horses, equipment and tracks used for hauling wagons, which preceded steam-powered railways. The terms "plateway", "tramway" and "dramway" are also used to describe this system. The advantage of using wagonways was that far bigger loads could be transported with the same power. These were mostly found in Germany in sixteenth and seventeenth

Fig. 2.1: Excavated Remains of Diolokos, The Rudimentary Railway

centuries and used to transport coal etc. Wagonways improved coal transport by allowing one horse to deliver between 10 to 13 tons of coal per run—an approximate fourfold increase. Wagonways were mostly designed to carry the fully loaded wagons downhill to a canal or boat dock and then return the empty wagons back to the mine.

The tracks of these wagonways were made of wood, which were fastened down, end to end, on logs of wood, placed crosswise at intervals of two or three feet. In time, it became a common practice to cover them with a "plating" of iron, to reduce friction and improve their life. The life of tracks improved but the life of wagon rollers shortened due to wear and tear. It was felt that wheels should also be made of iron and there is recorded evidence to suggest that iron wheel was used on wooden rail as early as in 1734. Cases of iron platings buckling under the pressure of loaded wagon were not uncommon and this led to development of iron rails. Though both the wheels and track were made of iron, yet the source of power continued to be animals, particularly horses.

Fig.2.2: Horse drawn railway carriage.

Passengers were also transported in horse driven carriages and goods like coal etc were moved using horses and in some cases with fixed engines at various intervals connecting the wagons with an arrangement of ropes and pulleys. The advent of steam engines changed the course further. When in 1804 the first recorded use of self propelled steam engine on a railway was done it was found more expensive than horses and there was apprehension that smooth wheels of steam engine may not grip well on the smooth rail. The first public railway which opened in 1805 in England used horses as a means of traction. After this 14 more railway lines were taken up in England till 1821 but Steam traction was not used in any one of them. Georege Stephenson's locomotives with certain improvements were used in Killingworth Colliery during this period and that gave the confidence to use steam engines for more usages. In the mean time Stockton and Darlington Project was started in England to connect the coal rich Durham area with the port. On 27 September 1825 the first train loaded with passengers and merchandise in the world was hauled with Steam locomotive from Stockton to Darlington. This first modern train was received with much acclaim and applause.

Liverpool and Manchester Railway was planned with the aim of linking the textile mills of Manchester to the nearest deep water port at the Port of Liverpool. Transporting raw cotton through the 56 km distance from Liverpool to Manchester was as expensive as the initial cost of shipping it from America to Liverpool. Although horse and human powered railways had existed for centuries the need for more efficient mode of power supply was felt. The authorities at Liverpool and Manchester Railway could not choose between stationary steam and locomotives as the preferred mode of power to pull the trains. Then it was decided to hold an open contest to see all the locomotives in action. The famous Rainhill Trials were thus conducted in October 1829.

Five locomotives namely Cycloped, Novelty, Perseverance, Sans Pareil and Rocket took part in the competition and only Rocket could complete the race. The speed of Rocket with the prescribed load was often eighteen miles per hour, and occasionally upwards of twenty and sometimes even touching thirty miles per hour. This was revolutionary at that point of time. This was a transition in accustomed rate of travelling from eight to ten miles an hour to fifteen or twenty or even higher. Thus the Rainhill Trails assumes a significant place in the history of train speed.

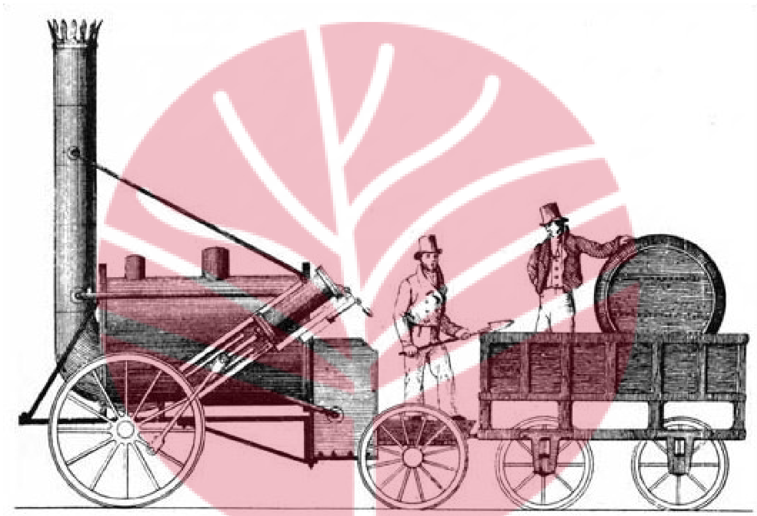

Fig. 2.3: Drawing of Rocket engine

The Liverpool Manchester line was opened in September 1830 with the 'Rocket' heading the inaugural train. This was the first railway to exclusively use steam engines. Now Steam locomotives became a regular feature of rail transportation

What made this leap possible? Traditional steam engines had serious limitations of capacity. It was not possible to generate enough steam to power heavier loads. George Stevenson made two significant changes in the design of Rocket. Instead of using a single pipe to transfer hot gases from furnace to boiler he used twenty five pipes. This multi-tubular structure increased the contact area and now the same amount of fire could generate much more amount of steam to power piston and wheel. Another improvement was recycling the steam, instead of allowing the steam to go out in air through piston it was made to pass through a long blast pipe making it more powerful.

In the 1830s a speed of 50 kilometer per hour was considered fast. When in 1845 the London to Exeter express averaged 70 kilometer per hour, it was considered as the fastest rail service in the world. In the late 1840s a train nicknamed as Flying Dutchman was introduced between Paddington and Didcot at an average speed of 90 kilometer per hour. For a considerable period of time this remained the top average speed of railway service. George Stevenson through the use of multi-tubular boiler and blast pipe had helped improve the speed of trains to a large extent but further improvements were not forthcoming.

Herbert Nigel Gresley who was Chief Mechanical Engineer of the London and North Eastern Railway and one of Britain's most famous steam locomotive engineers, attempted to study the factors limiting the speed of steam locomotives. He realized that aerodynamics plays a very important role and found that the wind hitting the face of locomotive was pushed sideways and was restricting the speed. Gresely designed the wedge shaped nose of the locomotives so that the locomotives can slip through the

Fig. 2.4: Mallard locomotive with aerodynamically efficient design

air and move faster. To make the trains aerodynamically efficient wheels were covered with streamlined panel and gap between carriages was covered with rubber sheet to prevent turbulence. These significant design improvements lead to a quantum jump in the speed of trains. These streamlined locomotives were called class A4 locomotives. One of its class 4468 Mallard achieved the world record speed of 126 miles per hour i.e 202.58 kilometer per hour in 1938.

Fig. 2.5: World record plaque of Mallard train.

This fact must not be missed that it was a mere trial run but the aerodynamically efficient design helped in further improving the commercial speed of trains.

When Japan started the project of Bullet trains engineers discovered that at very high speeds carriages were sliding in a snake like motion which was called hunting. Further research established the fact that the shape of the wheel could be the factor. Conical shape of the wheel was designed to keep the wheels on the track even at very high speeds. However mere shape was not enough and it was found out that suspension of wheel assembly too played a role. So ,steel springs were attached to keep the wheel on track. This design improvement helped Japanese bullet trains to achieve the speeds of around 185 miles or 300 kilometers per hour.

At such high speeds it was very difficult for the drivers to sight the signals, because it was necessary to improve signalling system to ensure safety. Cab signaling proved a boon as it was possible for the drivers to get the target speed and position of trains ahead in his cab. These features have revolutionized the rail transport system.

Early Developments

Search for high speed rail started in Germany in the early 1900s. The impetus for such research was the electrification of military owned railway between Marienfelde and Zossen. Two rail cars demonstrated that it is feasible to run high speed electric train, as one rail car achieved the speed of 206.7 km/h on 23 October 1903 and the other achieved the speed of 210.2 km/h on 27 october 1903 on the newly electrified line. Next notable development happened in Germany when 'Flying Hamburger' of 1933, ran between Berlin and Hamburg (286km) at an average speed of 125 kilometer per hour. This was the fastest regular rail service in the world with a maximum speed of 160km/h. In june 1936 the steam powered Henschel-Wegmann Train was developed and introduced as regular service from Berlin to Dresden with an average speed of 160km/h. These developments helped extend the usage of flying trains on different rail networks across Germany. Further research and development in high speed services stopped before the start of World War II.

At the same time when Germany was experimenting with high speed trains, in America the Burlington Rail road set a peak speed record of 185km/h for the diesel powered Zephyr train on 26 May 1934. The average speed of this service was 124 kilometer per hour. Zephyr Train was made of stainless steel and its coaches were articulated with Jacobs bogies. It had the commercial speed potential of 160 kilometer per hour. However due to various practical constraints the speed potential could not be realized and the regular commercial service between Kansas city and Lincoln which started on 11 November 1934 had the average speed of 74 kilometers per hour. In 1935, Milwaukee Road Company introduced the Morning Hiawatha Service, powered by steam locomotives at 160 kilometers per hour. These trains were the last high speed trains with steam locomotives. One year later in 1936 High speed train service between Chicago and Minneapolis was run with an average speed of 101 kilometers per hour.

The Italian ETR200 electric trains of 1936, which served the Bologna-Rome-Naples route were designed for 200 kilometer per hour. In 1938-39 these trains not only achieved 203 kilometers per hour in a demonstration run but also produced average speeds of 165 and 176kph on the Florence-Bologna-Milan route.

Cheltenham Spa Express run by Britain's Great Western Railway had the scheduled commercial average speed of 110 kilometers per hour in late 1920s. In the year 1938 in Great Britain the steam locomotive 'Mallard' achieved the official world speed record for steam locomotives at 202.58km/h. The Second World War brought to halt the progress regarding high speed rail systems. Further development started only after Second World War.

Fig. 2.6: Mallard train. Source: topbritishinnovation.org

In Spain, Talgo, manufacturer of intercity, standard and high speed trains patented the Talgo system. Talgo trains are known for their unconventional articulated railway passenger cars in which wheels are mounted in pairs but not joined by an axle and bogies are shared between coaches rather than individual coaches. This allows a railway car to negotiate turns at higher speed with less swaying. These articulated trains were able to run on existing passenger tracks at higher speed than contemporary passenger trains. Development of Talgo system was a great milestone in the field of high speed rail technology.

During 1940-50, SNCF (French National Railway) used the 2D2 locomotives, a Swiss model from the 1930s with a speed of 120-140 kilometers. During this period, France imported much of the technology for high speed trains from abroad. In 1950s the receipt of powerful CC electric locomotives generated keen interest in the running of high speed trains. In 1954, the CC 7121 engine of French National Railway while hauling a full train achieved a record 243 km/h during trial run on a standard track. In the year 1955, CC7107 and the prototype BB 9001, achieved record breaking speeds of 320 km/h and 331 km/h on standard track. This was first time when the speed of 300 km/h was achieved during trial run and this led to generation of ideas for start of scheduled commercial services at very high speed.

During the speed trial runs by SNCF a very dangerous hunting oscillation, the swaying of bogies was observed leading to dynamic instability and potential derailment. This led to use of Yaw dampers which enabled safe running speeds above 300km/h. Yaw damper is a transverse mounted shock obsorber used to prevent rail cars and locomotives from swaying excessively from side to side. Yaw dampers prevented locomotives and passenger rail cars from hitting against railway station platforms as they roll past them and reduce the gap that must be left between railroad vehicle and platform.

Shinkansen and the First Bullet Trains

In 1930, when Japan was considering high speed rail projects, its trains were running on narrow gauges largely due to terrain constraints. The project was known as Dangan Ressha which meant 'bullet train' in English.

The Shinkansen (new trunk line) project in 1940 proposed standard gauge passenger and freight line between Tokyo and Shimonoseki with a top speed of 200km/h. However as the world war II intensified, the project was basically shelved and forgotten for many years. The Tokyo Osaka corridor had become densely populated and congestion on both road and rail had become a serious problem. The area was populous but the resources were limited and Japan was not very inclined to import petroleum. That is how the process of building a new high speed rail service got expedited. Japanese Railway engineers studied all the development of high speed regular mass transit system. In 1957 Odakayu Electric Railway in Greater Tokyo created world record for narrow gauge trains at 145 km/h, which instilled a sense of confidence in Japanese Railway engineers, and Japanese Government accorded the approval for dedicated high speed rail system in December 1958 and the construction started in April 1959.

Fig. 2.7: Shinkansen train with Mount Fujiyama in the background.
Source: japan-guide.com

The Shinkansen line became operational on 1st October 1964, Just in time for the Tokyo Olympics. This was known as Tokaido Shinkansen. The conventional train Journey between Tokyo and Osaka took six hours and forty minutes but shinkansen shortened the trip to three hours and ten minutes by 1965.

Introduction of shinkansen changed the economy and social life of Japan. The service was a success as it touched 100 million passenger marks in 1976. This success led to network expansion of shinkansen.

Revival of high speed projects in other parts of the world

German Federal Railway known as D B (Deutsche Bundesbahn) practically demonstrated a daily high speed rail service at 200 km/h between Munich and Augsburg in June 1965. This demonstration could reach its logical conclusion in the year 1977 when a new service at 200 km/h could be started on the same section. After many trials from 1979 to 1989 at varying speeds ranging from 230km/h to 430km/h Germany launched the first ICE (Inter City Express) trains on lines between Hanover and Wurzburg (327 km) at a top speed of 280km/h in the year 1991. This German ICE train had dedicated streamlined power cars at both the ends with a variable number of trailers between them. These trailers had two conventional bogies per car and could be uncoupled, allowing the variation in train length. In 1999 ICE became capable of commercial operation at 330km/h and in the year 2003 trial run for ICE 3 was conducted at 501 km/h.

French National Railway SNCF began serious studies on high speed trains after 1955. However even after the success of Shinkansen (1964) at 210km/h and German demonstration up to 200km/h in 1965, SNCF‘s maximum speed was only 160km/h. In 1964 SNCF planned the use of diesel powered railcar modified with gas turbine. It reached the experimental speed of 230 km/h in 1967. In the same year after some engineering improvements like cab signaling, curve revisions, a regular service at 200 km/h was inaugurated between Paris and Toulouse on the conventional tracks.

TGV in French means “Train a Grande vitesse’, English equivalent of High speed train. SNCF developed a prototype named TGV001 consisting of an undividable set of 5 cars and 2 power-cars at both end each powered by Gas turbine engine. The special feature of this prototype was the use of Jacobs bogies shared by two cars which helped in reduction of drag and improvement of safety. In 1970 SNCF’s specially designed Turbotrain having the potential of 200 km/h was used at 160 km/h on Paris Cherbourg line. In 1971 French government gave the go ahead for TGV project. The 1973 oil crisis increased the oil prices substantially and French Government initiated various energy self sufficiency measures. Accordingly TGV development switched from gas turbine to electric energy in 1974. An electric rail car named ‘Zebulon” was developed for testing at very high speeds of around 300km/h.

In 1981, the Paris Lyon high speed line started operating at 260km/h. Further TGV created many high speed trial records like 380km/h in 1981, 515km/h in 1990 and 574.8km/h in 2007.

To revitalize the stagnant southern Spanish economy it was proposed in late 1980s to have a new rail link to Andalusia. It was also decided that the new line be a standard gauge and not the traditional Iberian gauge. Expo 92 in Seville and Olympics in Barcelona were the reason for expediency shown by the spain government in the implementation of high speed rail project. Spain was able to open the Madrid – Seville high speed rail line before these events.

In 2005 Spain announced an ambitious plan which envisaged that by 2020, 90% of the population would live within 50km of a station served by A.V.E. rail service. There after Spain started building one of the largest high speed rail networks in Europe.

AVE is the name of high speed rail system operated by Spanish national railway company. Spanish high speed rail system is the longest system in Europe and second longest in world next only to china.

First high speed section of Italy was Rome–Florence–Diretissima (means 'shortest link') which opened in 1976. Then in 1978 trial run at 250km/h was conducted. In 1996 an ambitious project of high speed rail route cutting across Apennines for a stretch of 79 km with 72 km of it in tunnels was started thus making it one of world's most expensive lines.

Only a year after the successful run of Shinkansen in Japan, USA enacted the High Speed Ground Transportation Act 1965 to explore the development of high speed rail in USA. This led to Introduction of Metroliners between Washington D.C. and New York city in 1969 with a top speed of 180-192 km/h. These were High speed Electric Multiple Units which were gradually replaced by locomotives hauled trains. National Railroad Passenger Association Known as **Amtrak** planned high speed rail services as a replacement for metroliners. Sincere efforts for development of High speed rail system started in USA in 1992 when the segment between Boston and New York City was chosen for upgradation of speed through electrification of the segment. Two trains namely Swedish X2000 and the German ICE 1 were tested between New York City and Washington DC. Finally a tilting train derived from TGV was put into service in December 2000.

This new service was called 'Acela Express' and linked Boston, New York City, Philadelphia, Baltimore, and Washington DC. It achieved a maximum speed of 241km/h on a small section of its route through Rhode Island and Massachusetts. With the increasing popularity of the Acela Express, the Metroliner service was phased out; the last Metroliner operated on October 27, 2006.

Seoul-Busan Axis is considered the main traffic corridor of

South Korea. Planning for a second passenger rail corridor on this line had started way back in the 1970s. Many studies were conducted and finally in 1989, the Korean Government decided to implement the high speed rail between Seoul and Busan for which construction started in 1992. It was decided that French TGV technology will be used. The operation started on 1 April 2004 on the Seoul–Busan Corridor. This service was called Korea Train Express (KTX).

Currently the top speed of KTX in regular service is 305 km/h. The next generation KTX train, HEMU – 430X achieved 421.4km/h in 2013, and thus South Korea became the world's fourth country after France, Japan and China to develop a high speed train running on conventional rail above 420km/h.

The earliest example of high speed rail system in china was Asia Express which operated in Japanese controlled Manchuria from 1934-1943. Asia Express was a steam powered train with maximum permissible commercial speed of 110 km/h. After the discontinuation of service in 1943 there was not much progress as far as the speed of Chinese railway was concerned.

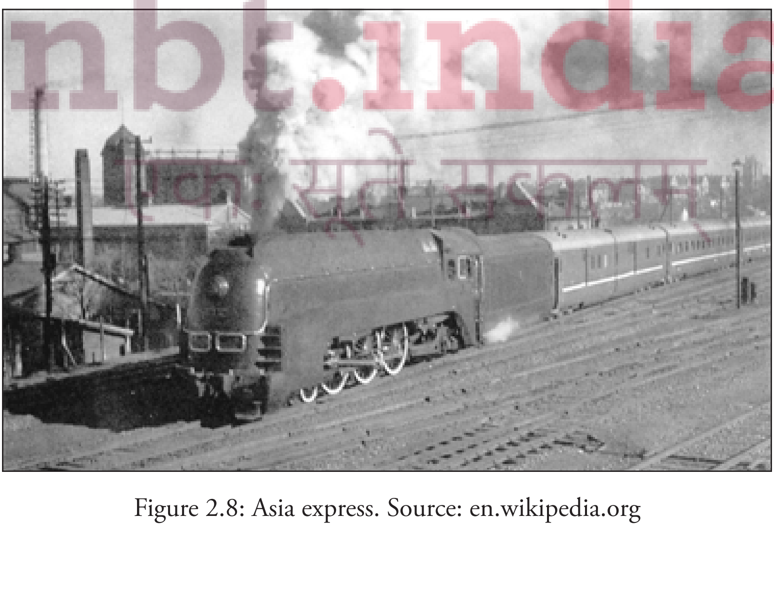

Figure 2.8: Asia express. Source: en.wikipedia.org

The average speed of Chinese railway trains remained very low. It was 48 km/h in 1993. Thus Chinese railway was unable to compete with airline and roadways. Chinese Railway attempted traditional modernization measures like doubling, electrification, grade smoothening, curve realignment, use of continuously welded rails etc. This led to marginal improvement in average speed. The Chinese ministry of railways launched a project to raise the speed of railway travel in China. The project was implemented in six rounds from 1997 to 2007. Guangzhou-Shenzhen Railway line was electrified in 1998 and Swedish made X 2000 trains increased the service speed to 200 km/h. By 2007 this line had four separate tracks and high speed passenger and freight trains were running on separate tracks. As a result of which travel speed increased on 22000 extended km of the Chinese rail network and the average speed of passenger trains improved to 70 km/h. The planners were also concentrating on the development of dedicated high speed rail corridors.

Conventional Rail versus Maglev technology debate had assumed significance since 1998. Maglev is a method of propulsion which uses magnetic levitation to propel vehicles with magnets rather than with wheels, axles and bearing units. In Maglev system, a vehicle is levitated a short distance away from a guide way using magnets to create both lift and thrust. This system does not rely on traction and thus acceleration and deceleration can surpass that of wheeled transports.

The debate tilted in favor of Maglev technology when in 2000, the Chinese government decided to purchase a turnkey Transrapid train system from Germany for the 30.5 km rail link between shanghai city and its international airport. This Sanghai maglev train achieved the distinction of being the world's first commercially operated high speed maglev in 2004. It runs at a peak speed of 431 km/h.

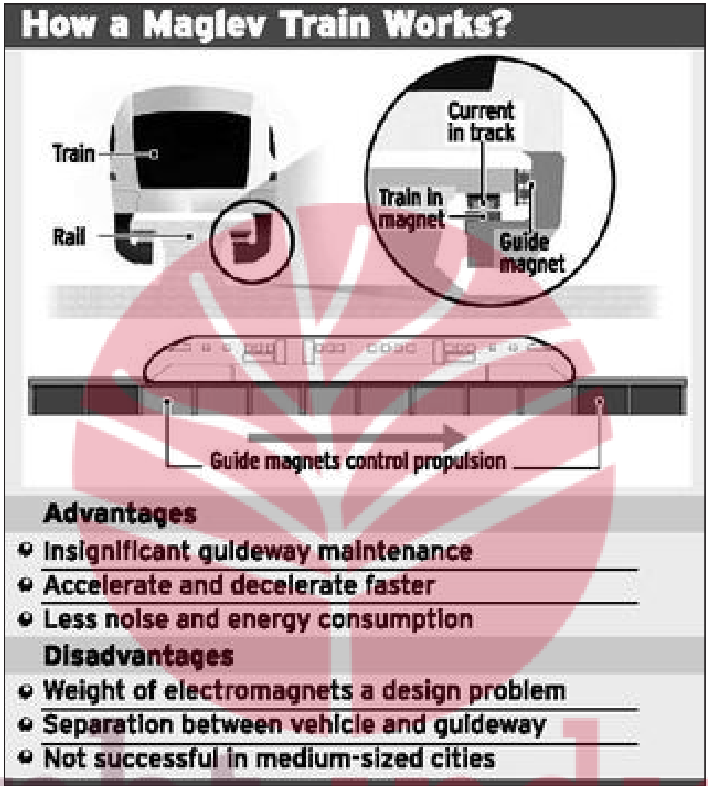

Figure 2.9: Maglev train technology simplified. Source: thehindu.com

Maglev has unmatched speed advantage but it could not gain popularity as Germany refused to share the technology with China and its exorbitant cost along with safety and environmental concerns halted its further progress. Further development of high speed rail in China happened with conventional rail only.

The other issue which became controversial was the acquisition of foreign technology. Initially Chinese government planned to adopt Shinkansen technology as it had a successful track record. But the issue of developing Chinese high speed rail system with Japanese technology got politicized and there were

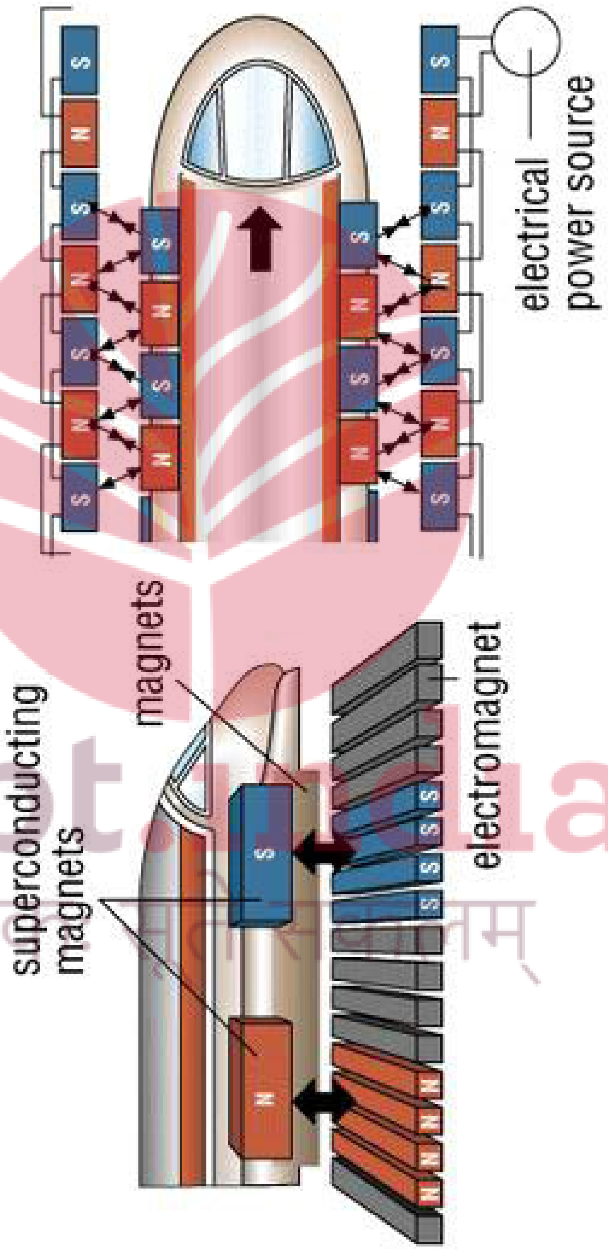

Figure 2.10: Maglev technology. Source: wou.edu

massive campaigns to oppose the adoption of Japanese technology. The reasons were historical rather than economical. Chinese people were against Japan as it had allegedly committed excesses during the second world war. These protests led to adoption of a diversified approach and Alstom of France, Siemens and Bombardier of Germany and a Japanese consortium under the leadership of Kawasaki were awarded portions of high speed rail contract. All these agencies had to assemble units through local joint ventures and all High speed train sets to be as per China's standard. Chinese government after receiving transferred foreign technology decided to develop indigenous capability by producing different key parts and improvising upon foreign designs.

Till 2007 the Qinhuangdao –Shenyang passenger line with a top speed of 250 km/h was the only High Speed rail line in China. This line was opened for commercial operation in 2003 with a design speed of 200 Km/h. After 2007 China embarked on a high speed railway construction boom and by 2011 China had the world's longest high speed rail network with 8358 km of routes fit for 200km/h or more. Out of these 2197 km of rail network had the capacity of a top speed of 350 km/h.

Corruption and Accidents in High Speed Rail Project of China

In February Chinese Railway Minister Liu Zhijun was removed from office on the charges of corruption in high speed rail projects. This incidence generated debate regarding safety, higher ticket prices, financial sustainability and environmental impact of high speed rail projects. To make matters worse, on 23 July 2011, two high speed trains collided in Wenzhou resulting in many deaths. The corruption issue along with the unfortunate accident created public uproar. Consequently the speed on many sections were reduced and there was sharp reduction in High speed rail ridership. Lending banks began to cut back on lending to rail construction projects. Thus new projects were put on hold and completion dates of existing projects were shifted. The Chinese government renewed investments in high speed rail in the year 2012 to give a boost to high speed rail system which led to recovery in construction and by December 2013 the high speed rail network length was close to 10000 km.

Development in India

According to train nomenclature, some of the names used to classify Indian railway trains include passenger trains, express trains, superfast trains, Rajdhani express and Shatabdi express. The basic distinction is that of speed. Express trains have an average speed excluding halts, over 36 km/h and the average speed excluding halts for superfast trains is 55 km/h. Rajdhani express are trains connecting important Indian cities and the capital city New Delhi. These trains have a maximum permissible speed of 140 km/h. The first such train was introduced between New Delhi and Howrah in the year 1969. Since then the economical and technological progress of India necessitated a thinking for development of high speed rail system.

A feasibility study with the active association of JICA (Japan International Corporation Agency) was conducted for Delhi – Kanpur section via Agra to run the trains at 250 km/h. JICA in its report submitted in 1987 suggested a new high speed corridor with terminal stations at Delhi, Agra and Kanpur. RITES(Rail India Technical and Economic Service) an engineering and consultancy Public sector unit of Ministry of Railways conducted a feasibility study for Ahmedabad-Vadodara-Mumbai-Pune section.

Indian Railways Research wing RDSO (Research Design and Standardization Organization) in its first governing council meeting in 1988 had planned for developing technology for passenger train services at 160 km/h on mixed routes and at 200 km/h on dedicated high speed routes. RDSO also set up a task force to study all the aspects of high speed technology. Furthermore three corridors were studied by RITES for high speed services, these included:

i) Mumbai – Ahmedabad (492 km)
ii) New Delhi – Kanpur – Lucknow(507 km)
iii) New Delhi – Agra (192 km)

Based on the anticipated traffic Mumbai–Ahmedabad section was found to have the best potential, however the cost factor was very prohibitive. In 1987 it was estimated to cost about Rs. 4.7 crore per km. and the mission was closed. Integrated Railway Modernisation plan(2005-2010) envisaged passenger trains running at 150 km/h on New Delhi-Chennai and New Delhi-Howrah route.

Vision 2020 of Indian Railways prepared in December 2009 which was subsequently submitted to the Parliament envisaged "The first approach would be to raise the speed of segregated passenger corridors on trunk routes using conventional technology from 160 to 200 Km/h. The second approach would be to identify a number of intercity routes, depending on viability, and build state-of- the-art high-speed corridors for speeds up to 350 Km/h on Public Private Partnership mode in partnerships with the State Governments. Partnerships with the State Governments would be crucial as real-estate development would be a key element of viability of these high-cost projects. By 2020, at least four corridors of 2000 Kms would be developed and planning for eight other corridors would be in different stages of progress."

The Ministry of Railways had appointed an Expert Group on the Modernization of Indian Railways under the chairmanship of Mr. Sam Pitroda. The Expert Group presented its report in 2012. The expert group recommended to Construct a High Speed (350 km/h) railway line between Ahmedabad & Mumbai within the next 10 years at an estimated cost of Rs. 60000 crore.

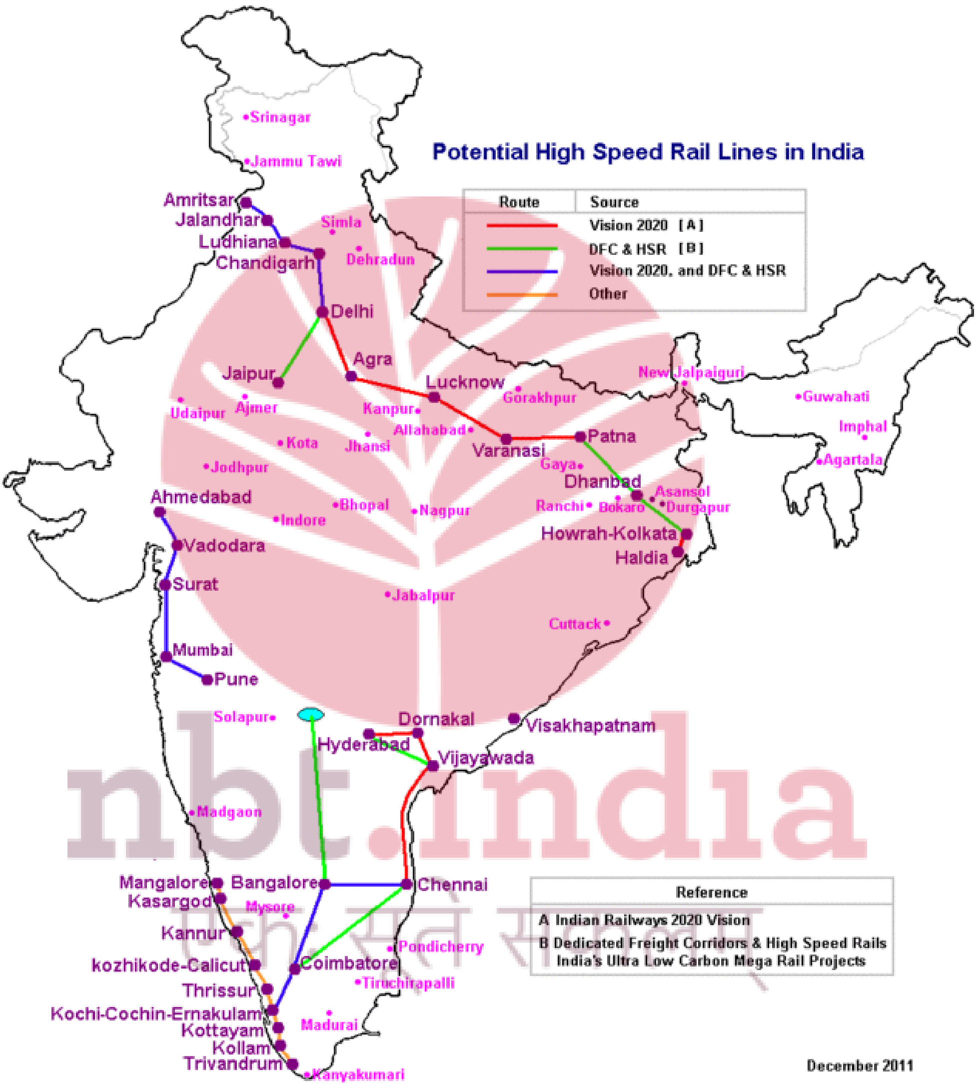

Figure 2.11: Identified high speed rail lines till 2011.
Source en.wikipedia.org

Indian Railways set up High Speed Rail Corporation of India in 2012 to deal with high speed rail projects. This corporation will handle tendering, pre – feasibility studies, awarding contracts and execution of the high speed rail projects in India.

The history of high speed rail projects indicate that with economical and technological progress all major rail systems of the world attempted to adopt the modern high speed rail technology in their busiest and economically important sections. In the beginning of this chapter we got a glimpse of technological progression to achieve the speed which is possible now. It will be appropriate to understand the bullet train technology in greater detail.

3

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Technological Details of Bullet Train

There is no single standard definition of Bullet Trains and there is no standard usage of the terminology high speed or very high speed. The **one generally acceptable definition** has been provided by European Union Directive which states that **high speed rail is a set of three elements** with the following three criteria:-

1. Infrastructure

a) The infrastructure of high speed system will include:

- rails built specially for high speed travel.
- rails specially upgraded for high speed travel. They may include connecting lines, in particular junctions or new lines upgraded for high speed with town centre stations located on them. The speed must take into account the prevailing local conditions.

b) High Speed lines shall comprise:

- specially built high speed lines equipped for speeds generally equal to or greater than 250 km/h.
- specially upgraded High Speed lines equipped for speeds of the order of 200 km/h.
- specially upgraded High Speed lines which have special features as a result of topographical, relief or town-planning constraints, on which the speed must be adapted to each case.

2. Rolling stock

The High Speed advanced-technology trains shall be designed in such a way as to guarantee safe, uninterrupted travel:

- at a speed of at least 250 km/h on lines specially built for high speed, while enabling speeds of over 300 km/h to be reached in appropriate circumstances,
- at a speed of the order of 200 km/h on existing lines which have been or are specially upgraded,
- at the highest possible speed on other lines.

3. Compatibility of infrastructure and rolling stock

High Speed train services presuppose excellent compatibility between the characteristics of the infrastructure and those of the rolling stock. Performance levels, safety, quality of service and cost depend upon that compatibility.

As per International Union of Railway (UIC), today the high speed rail system is operational in 15 countries with a total rail network of 21,161 km.

Sl No.	Country	Operational kilometer
1	China	9867
2	Japan	2664
3	Spain	2515
4	France	2036
5	Germany	1334
6	Italy	923
7	Turkey	444
8	South Korea	412
9	USA	362
10	Belgium	209
11	The Netherlands	120

12	United Kingdom	113
13	Austria	93
14	Switzerland	35
15	Taiwan	34

Besides, Poland,Portugal, Russia, Morocco, Saudi Arabia, Brazil and India are planning for High Speed Rail System.

Bullet trains are technological wonders of the world. Some of the basic questions it raises are: Will it run on the same track? What about bridges and tunnels? Will they be designed differently? Can the same railway coaches be used? How will the train driver observe signals at such a high speed? Will there be separate locomotives? What about safety, how will it be ensured?

High speed trains are run on the most modern technology. It is a complex system and requires state of the art components. These include:

- Physical settings like Grade, Tunnel, Bridge, Track, station design etc.
- Electrification system i.e. The power supply system and the Rolling Stock which in common parlance is known as railway coaches
- Operating and Signalling System

Each of the technological components will be discussed separately.

1. Physical Settings for Bullet trains

The high speed rail system must be separated from other modes of traffic. Thus there should be grade separation from the surface. This can be done by adopting an underground system or elevated system by constructing viaducts. The other systems can be conventional grade system or semi elevated system. These options are discussed separately.

(i) Underground System: Adoption of underground system is the costliest. The cost considerations make the option feasible only if the land is not available for construction of elevated system or there are environmental or aesthetical consideration necessitating the adoption of underground system. There are two ways of constructing underground systems. The first one is called Cut and Cover method. Under this method the area is excavated in the shape of trenches and formation is made ready, track for running of trains is laid and power supply system is provided and then the trenches are restored and ground is covered. As the ground is first Cut and then covered so this is called Cut and Cover method.

The other way of constructing underground system is through boring tunnels deep below the ground. Tunnel Boring Machines are used for this purpose.

The underground system allows for efficient utilization of land which otherwise can be used for other purposes. In this system, the train services can run without any interruptions like crossings etc. and frequency of the train is higher so the passenger carrying capacity is very high. The main disadvantage of underground system is its high cost. Moreover special care has to be taken for drainage and ventilation systems. Even during construction stage many essential utilities need to be diverted to avoid inconvenience to common public.

(ii) Elevated System: This type of high speed rail system is run at an elevation which is generally more than eight meters. The track is laid on a deck supported by columns. This is also called viaduct. The columns are built on the central verge of the road or the edge of the Right of Way and thus the system can pass through congested areas as well. Even the platforms and stations are constructed at an elevation. However, the elevated system carries with it the limitations namely high noise pollution and any accident may cause very high loss of lives and property.

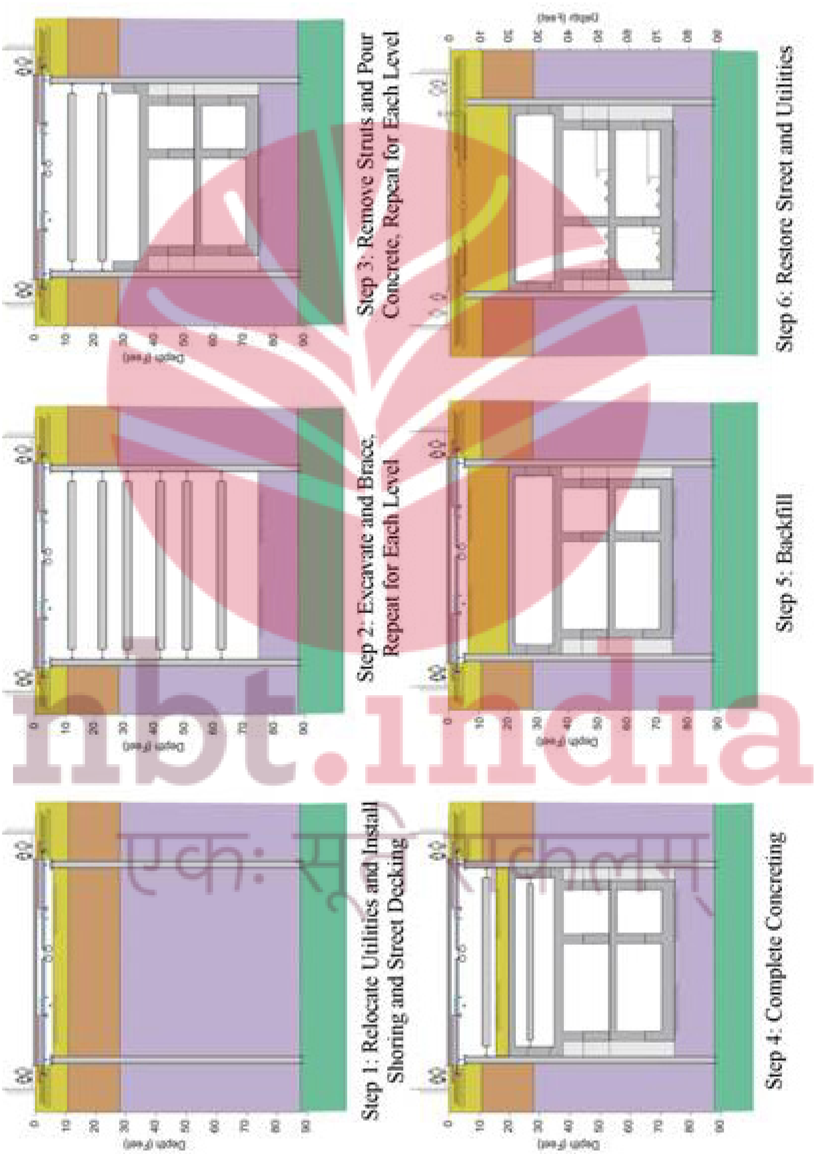

Fig. 3..1: Schematic Cut and Cover diagram.

Fig. 3.2: Elevated Viaduct system

(iii) At Grade System: This is the conventional system under which the ground itself is raised slightly and tracks are laid. As the tracks are on ground so the requirement of Road Over Bridges (ROB) and Road Under Bridges (RUB) is manifold. Problems of cattle crossings and trespassing are serious issues to be tackled with. In view of safety and security requirements proper fencing is a must for the success of this system.

(iv) Semi-elevated System: The structure is similar to elevated viaduct system with much lower heights i.e. around 2.5-3.0 meters from the ground. The lines are provided with a vertical wall of around two feet to protect it from trespass. At villages and colony roads where only Light motor vehicles are expected to cross, a railway over bridge (ROB) with 3-3.5 meter height is provided for crossing. This system has the advantage of being cheaper than the conventional grade system and has less land requirement as compared to elevated system. This system limits the scope of growth as once the road traffic increases it may not be possible to create grade separators or ROB or RUB.

Tracks for High Speed Rail Network

The two rails on which the trains run is collectively called Track along with all its components which keep the rails together and allow the train to run smoothly.

The tracks are of two types Ballasted tracks or Ballast-less tracks. Ballasted tracks have traditionally been provided since the beginning of railways. Ballast-less tracks have high construction cost but reduced maintenance cost.

Features of ballasted tracks: In this type of track rail fasteners fix track panels on the track bed covered with ballast. This type of tracks have advantages like low construction cost,ease of repairing, low noise and vibration.

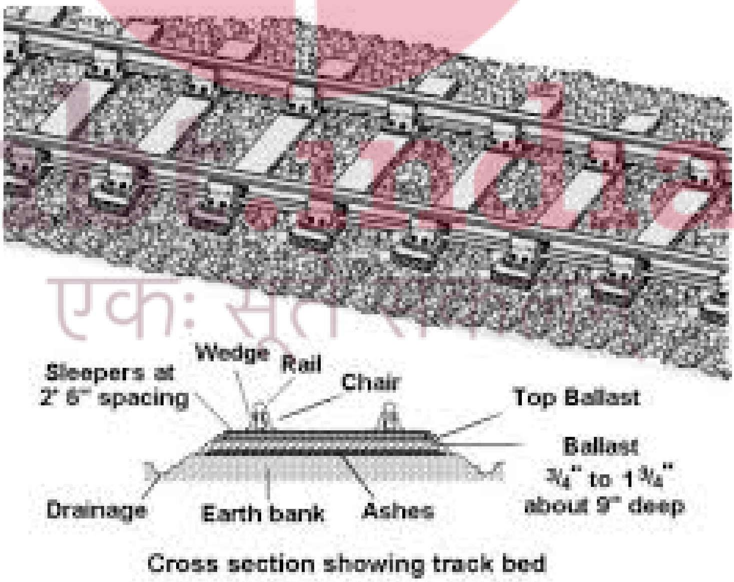

Fig. 3.3: Schematic diagram showing Ballasted track

Its limitation include frequent maintenance requirement which gradually increases with passage of tonnage. Moreover when a train runs at high speed ballast may fly due to high wind pressure. To control this track bed stabilizers are used.

Features of ballast-less tracks: The increase in the number and frequency of trains necessitated increase in volume and cost of ballasted track maintenance. This led to development of ballast-less tracks. These tracks are basically slab tracks. These slabs may be reinforced concrete or pre-stressed concrete. Reinforced concrete is basically concrete reinforced usually with steel bars to improve the strength. Pre-stressed concrete is prepared by providing a clamping load to produce compressive stress on the steel bars and the concrete is cast around the pre-stressed bars. The construction cost of ballast-less track may be two times that of ballasted tracks but it has the advantage of reduced operational cost over a long period of time. Bogl Track is a type of ballast-less track and is used in some parts of Chinese high speed rail system. Similarly Rheda track is also a version of ballast-less track and are used for high-speed railways in Spain, the Netherlands, Korea, Taiwan and China.

Track gauge is the distance between two rails. The track gauges are of different types in different parts of the world. The following table presents the description of different types of Track gauges.

Gauge	Name	Main Countries.
1676 mm	Broad gauge or Indian gauge.	India, Pakistan, Sri lanka, Argentina, Chile.
1668 mm	Iberian gauge.	Spain (excluding high speed lines.) Portugal.
1600 mm	Irish gauge	Ireland, South Australia, Brazil.

1524 mm	Russian gauge.	Finland
1520 mm	Russian gauge	CIS states.
1435 mm	Standard gauge	Europe, USA, Canada, China, South and North Korea. Middle east, High speed lines in Spain and Taiwan.
1000 mm	Meter Gauge	SE Asia, India.

Different types of track gauges

Almost sixty per cent of the world's railway use standard gauge and most of the high speed rail tracks are of standard gauge.

Rails are produced in fixed lengths and need to be joined end-to-end to make a continuous surface on which the trains run. The conventional method of joining the rails is to bolt them together using metal fishplates. These tracks are called Jointed tracks. Small gaps known as expansion joints are deliberately left between the rail ends to allow for expansion of the rails in hot weather.

Fig. 3.4: Jointed tracks.

The rails in this grade system are short in length and are joined together with small gaps between each rail. These jointed tracks are unsuitable for high speed operations as it is difficult to maintain such large number of joints and bolts. Due to breakage of joints possibility of accidents are more. Thus these type of tracks cannot support high speed operations.

For high speed trains, the lengths of rail may be welded together to form **continuous welded rail** (CWR). In this form of track, the rails are welded together through the process of **flash butt welding** to form one continuous rail that may be several kilometers long. In this type of welding the pieces of rail to be welded are set apart at a predetermined distance and current is applied to the rail, and the gap between the two pieces creates resistance and produces the arc required to melt the rail. Once the pieces of rail reach the proper temperature, they are pressed together, effectively forging them together. As no filler material is used, these welds are very strong. This smoother rail reduces the wear on the rails themselves, effectively reducing the frequency of inspections and maintenance.

Fig. 3.5: Continuously welded rail.

Rails being metal have a tendency to expand in hot conditions and contract in cold weather. To take care of this the rail is prevented from moving in relation to the sleeper by use of clips which resist longitudinal movement of the rail. There is no theoretical limit to how long a welded rail can be. However, if longitudinal and lateral restraint are insufficient, the track could become distorted in extreme weather conditions. To prevent such distortions Continuously Welded Rail and its fastening is laid at a temperature roughly midway between the extremes experienced at that location. This stressing procedure prevents tracks from buckling in hot conditions or pulling apart in cold conditions.

The other important track parameter is cant which may be defined as the difference in elevation or height between two rails. It helps train steer around a curve keeping the wheel flanges from touching the rails, minimizing friction and wear. The cant helps to distribute the rail across both the rails, it reduces rail and wheel wear, neutralize the effect of lateral forces and improves passenger comfort.

There is only one speed for a particular curve for which super elevation would be correct. For example on a curve of radius 4000 m on standard gauge track, goods train running at 80 Km/h would need an equilibrium cant of only 19 mm, whereas high speed passenger trains running at 300 Km/h would require an equilibrium cant of 265 mm. These are conflicting requirements and a compromise value at design time will not serve the purpose as the permissible limits of both cant deficiency and cant excess will be violated. Thus trains on high speed rail network should not have much speed differential.

The other important aspect related with cant is derailment and passenger comfort. Cant should be proper to ensure that vehicles are not offloaded during run whether at prescribed speed or stationary or at very low speed. At the same time passenger should not feel any discomfort when the train is on a curve. For high speed rail in Europe, maximum cant is 180mm and slow freight trains are not permitted on these tracks.

Apart from the cant or super elevation cant deficiency and cant excess is required to be understood. Equilibrium speed of the train is the speed at which the effect of centrifugal force is exactly balanced by the cant provided. Corresponding cant for a given radius of curve and given vehicle speed is called equilibrium cant (C_{eq}). It may not be possible to allow trains to run at a fixed speed always on a curve. It is possible that train stops or runs slowly in a curve. Therefore, the maximum cant has to be limited. When the actual cant provided is less than the equilibrium cant (C_{eq}) cant deficiency (C_d) arises. The cant deficiency is the additional cant that is needed to achieve equilibrium cant.

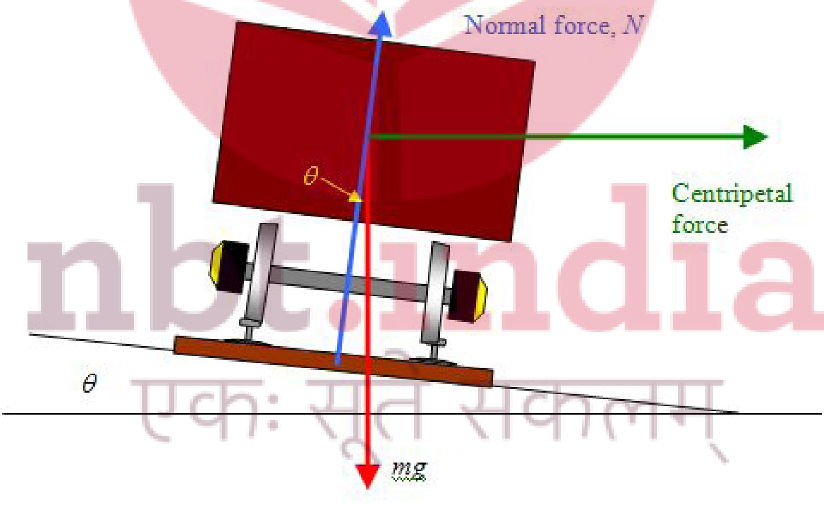

Fig. 3.6: Super elevation.

Limiting value of cant deficiency for lines specially built for high speed without tilt is 100 mm for speed range between 250 Km/h to 300 Km/h; and for speed over 300 Km/h the limiting value is 80 mm.

Cant excess (C_e) represents the unbalanced lateral acceleration. It occurs when a vehicle travels round a curve at a speed lower than the equilibrium speed. It is the difference between actual cant and theoretical cant required for such a lower speed. Generally 110 mm is the recommended limiting value and 130 mm is the maximum limiting value for cant excess.

Rate of cant deficiency describes the change of lateral acceleration as a function of time. This is also called lateral jerk. This has direct bearing on passenger comfort. The recommended limiting value for High Speed lines with dedicated passenger traffic is 50 mm/sec.

Cant gradient indicates the amount by which cant is increased or reduced in a given length of transition e.g. 1 in 1000 means that a cant of 1 mm is gained or lost in every 1000 mm of transition length.

The generally recommended limiting value is 2.25 mm/m but this value is not very critical for high speed operations.

Gentle horizontal curves are generally adopted on high speed tracks. The maximum radius of curvature for the various high speed lines in different countries varies from 4000 m to 7000m for standard gauge. As passengers are subjected to lateral acceleration while traversing horizontal curves, so the specified limits are essential. Similarly the vertical acceleration (upward in case of summit and downward in case of sags) causes discomfort to the passengers if its intensity exceeds some specified limits. The specified limit for vertical acceleration is 0.3 to 0.45 m/sec^2. Consequently the design value for vertical curve radius may be 0.4V^2 and limit value may be 0.25V^2.

It is not only the layout and design of track which is important but the various components of tracks are also equally important. Rail is the most vital component of the track. Rail has to be 60 Kg 90 UTS type. 60 Kg means that the weight of one meter of rail is 60 Kg and 90 UTS means ultimate tensile strength of 90

Kg/mm^2. The rails need to be continuously welded (CWR) to improve the ride quality and to reduce noise and vibrations.

Pre-stressed concrete sleeper with a sleeper density of around 1666 sleepers / Km is considered appropriate for high speed rail.

Rail pads, fastening systems and stiffness of the track must be appropriate in order to reduce the vertical dynamic forces between wheels and rails. For ballasted high speed rail tracks, the dynamic rigidity of rail pads should not exceed the specified value of 600 MN/m. Similarly, the total dynamic stiffness of slab track systems should not exceed 150 MN/m.

Turnout is a mechanical installation on track enabling railway trains to be guided from one track to another. Special consideration is needed for the high speed rail movement over Turnouts like tangential layouts, thick web switches, moveable nose crossing, flatter angle of crossings etc. If the Turnouts are designed in such a way, passenger comfort and safety can be maximized.

While discussing curves and turnouts for high speed rails, it is important to understand the **concept of tilting trains**. As a train rounds a curve at high speed, objects inside the train experience inertia. This can cause luggage to slide about or seated passengers to feel crushed by the outboard armrest due to its centripetal force. Due to above factors passengers who are standing tend to lose their balance. Tilting trains are designed to counter this discomfort. In a curve to the left, the train tilts to the left to compensate for the force push to the right and vice versa. The train may be constructed in such a way where either inertial forces cause the tilting (passive tilt), or it may have a computer controlled mechanism (active tilt). Examples of active tilting trains operating at 200 Km/h or more on upgraded track include the Acela Express in the USA, the X 2000 in Sweden, the Pendolinos and Super Voyagers on the West Coast Main Line in Great Britain and the ICETD in Germany. Modern tilting trains are at an advantage from the state of the art signal processing

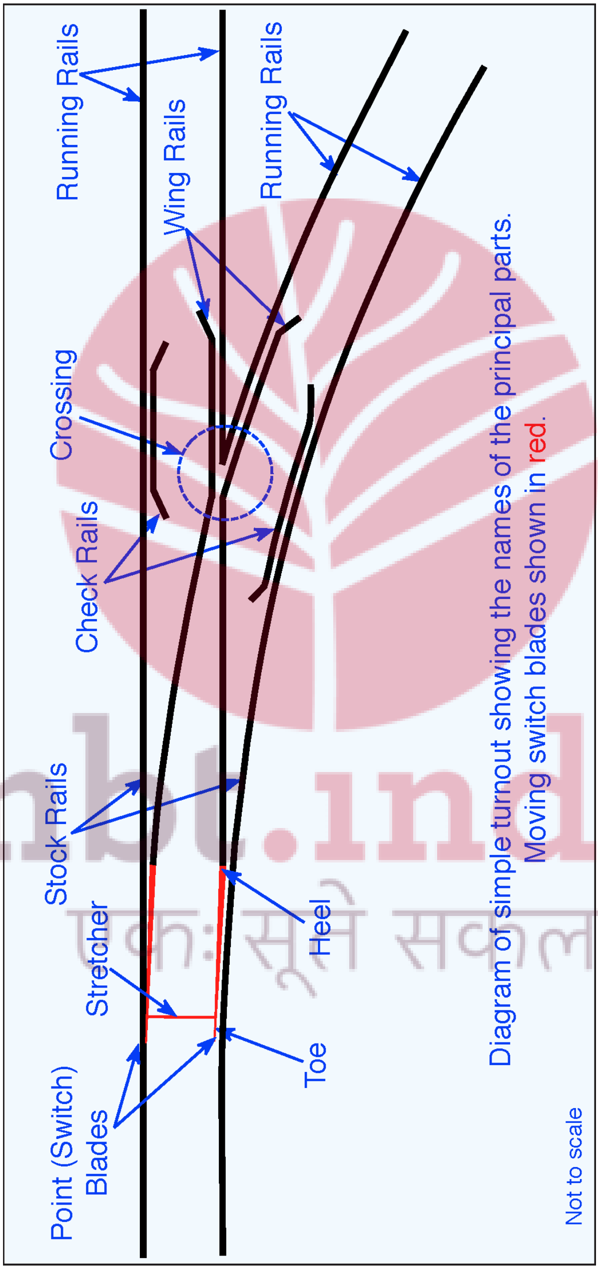

Fig. 3.7: Simple Turnout of railway track

which senses the line ahead and is able to predict optimal control signals for individual carriages.

Tunnels and Bridges for the High Speed Rail networks need to be specifically designed. When the train enters the tunnel at a very high speed, a compression wave is formed at the entrance of the tunnel. This wave travels through the tunnel and when it reaches the exit, a portion of it radiates outside as pulsed compression wave. This causes an explosive sound during the entry and may be painful and harmful to passengers. The explosive sound may shatter windows doors etc. To avoid such effect it is necessary to increase the cross sectional area of tunnel so that sharpness of aerodynamic forces are minimized. Coaches of High Speed rail should be air sealed so that micro pressure waves do not cause any harm inside the coach. Specially designed tunnel hoods & provision of pressure release shaft along the tunnel are important parameters while designing tunnels for high speed trains.

Fig. 3.8: Tunnel on Nuremberg–Munich high-speed rail route.
Source: en.wikipedia.org.

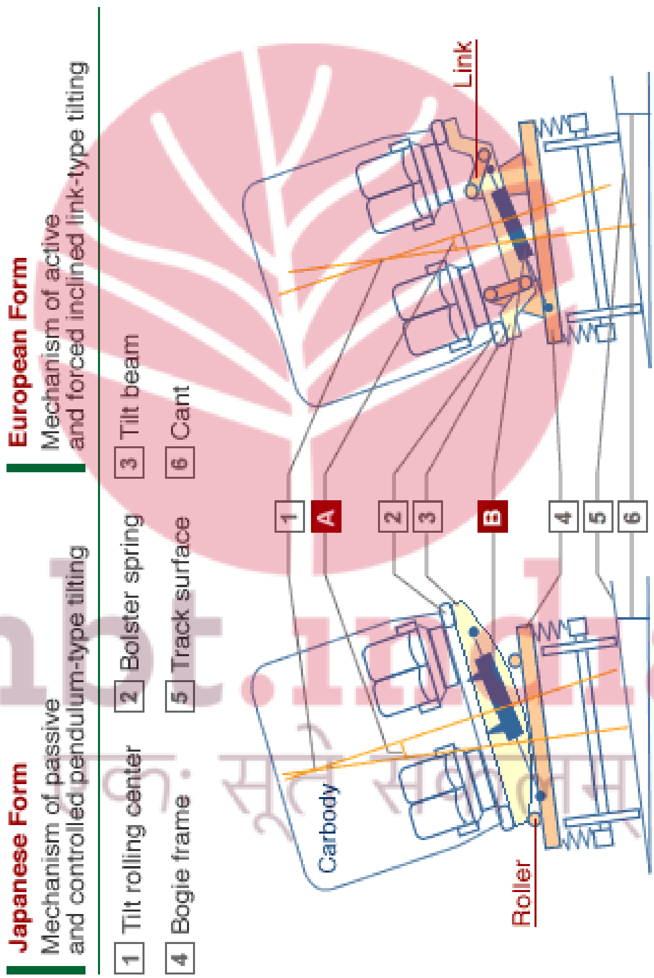

Fig. 3.9: Tilting train conceptual diagram

On High Speed Rail networks the bridges as well as bridge approaches becomes a vulnerable point. Piers should not be placed close to points, crossings etc and protection for columns should be provided and expansion devices on viaducts to be minimized or eliminated if possible.

Fig. 3.10: High speed train on Grand Weinan Bridge, China.
Source: Xinhua Agency

Station Layout and design is an important part of physical infrastructure for the bullet trains. Station design must consider various areas related to stations and flows of users. These areas include concourses, passages, staircases, elevators, escalators, ticket offices, ticket barriers, information desks, waiting rooms, toilets, ease of changing trains between different lines, as well as convenience of using public transport and parking lots.

Furthermore, the locations and structures of platforms are important, as stations should conveniently allow users to properly enter, and exit stations and trains.

Stations require facilities to monitor trains and boarding/ alighting passengers, with tracks in the station premise laid as straight as possible to ensure unobstructed views. Stations are important not only for railway users but also for train operation. Services must allow shuttle operations at major and intermediate stations and siding or overtaking at other midway stations

In addition, stations require offices, technical rooms, stores, safety equipment, train crew control and other facilities for railway operation.

High speed railway stations will have simpler track layouts compared with the stations of conventional railways where train operation patterns are of complex nature as both passenger and freight trains operate and there is high degree of differences in speed.

Allowing a high speed train to overtake a low speed train is normally done at stations where tracks for non-stop trains exist in addition to those having platforms for passengers. The tracks for non-stop trains are called the main line, and those where trains stop are called loop line. Overtaking and siding for this purpose require turnouts and signal equipment for setting and displaying routes, along with tracks of sufficient length to accommodate train-sets.

By now we have understood that tracks for bullet trains need to be designed with due care by giving special emphasis on points and crossing, turnouts, curves, super elevation tunnels and bridges etc. Some of the recommended infrastructure features as per UIC study are summarized below:

Flying Ballast phenomenon study should also be carried out. Crossovers should be available at each 20-30 km and sidings should be available at each 30-40 km. Turnouts should have length greater than 200 m with movable frog crossing. Maximum gradient should not exceed 40 ‰ and Maximum axle load should not exceed 17 ton. Minimum radius may be in the range of 3000-7250 mts and the length of horizontal and vertical transition curves should be high. Maximum cant should be in the range of 160-180 mm. This is to be borne in mind that these are recommendations but the actual values differ depending on various factors.

Apart from track the design for electrification and rolling stock must be done meticulously so that it meets the requirement of high speed rail system.

Electrification and Rolling Stocks for High Speed Rail

General public believe that high speed train require a lot of energy to operate. There are two ideas relating to the links between energy and the railway operation of trains that are very widespread, even among many highly educated people including railway experts.

a) The first idea called the "cube rule", is that the power of the train would increase with the cube of its speed.

b) The second idea, which is called the "energy rule" or "square rule", indicates that energy consumption would increase in proportion to the square of the speed.

This common misconception is used as a pretext to criticize the high speed rail projects. But how can we miss the simple fact that the fuel consumption of a car within the city limits, with an average speed of 40 km/h, is about 60% higher than the same car's consumption in the intercity driving with an average speed of 100 km/h. The same occurs in the case of buses and coaches: in urban services (20 km/h) the energy consumption is approximately 30% more than on intercity routes with average speeds of around 70 km/h. The empirical studies throughout Europe have proved that the trains that run at higher speeds consume less energy.

The running train gets power through overhead electric system. The system consists of overhead conductors suspended above the rolling stock and the vehicle is fed the electric power from overhead equipment by pantograph. Pantograph is a collapsible device mounted & insulated from the roof of an electric Engine or motor coach and provided with a means for collecting current from Over head equipment. On conventional railway system generally the 25 KV AC traction system is used. The electrification system for high speed rail system must be different. The typical 25kv booster system is not well suited for high speed rail network as the trains running at high speed draws power that results in arcing at booster overlaps as the pantograph temporarily short circuits the boosters while negotiating the overlap. The voltage regulation of the line is poor in the 25 KV booster system in view of very different power demand. To overcome their problems 2×25 KV auto-transformer system employs a negative feeder throughout the section and Autotransformers at an internal of 10-15 kilometers. Thus the voltage profile of the line is very good and the negative feeder is quite effective in suppressing the magnetic field of the line. Most of the High Speed Rail networks uses 2×25 KV AT system of electrification as it offers better voltage profile and interference level, and has more symmetrical loading and ability to provide for very high power demands.

Fig. 3.11: Overhead traction equipment or Pantograph.
Source: railway-technical.com.

Overhead traction equipment needs to be carefully chosen for the high speed rail network depending on the requirement of power transfer for maximum operating speed, spread of speed among various trains in the corridor, number of pantographs per train and their spacing. Contact wire is generally made of either, tin copper, silver bearing copper or copper clad steel wire (for tensions of 20kn). The tension in contact wire and catenary wire are in the range of 15KN (in French High Speed lines) to 20 KN (In Shinkansen Lines). With the exception of Germany, where the voltage is 15 KV at 162/3 Hz, other countries have adopted the system of 2×25 KV at 50 Hz. These power systems are suitable for speeds up to 350 Km/h.

The pantographs of high speed trains are generally lighter and differ in their very geometry compared to the pantographs of conventional electric rolling stock. Pantographs and insulators installed on the roof of the car are major source of noise at high speed, thus simple light weight single arm pantographs or ring shaped current collector which significantly contribute towards noise reduction are employed. Pantograph covers reduces the aerodynamic sound. Adoption of 25 KV bus couplers results in better current collection and reduction in noise.

Pantograph noise was a serious issue especially for Shinkansen as the trains ran through dense neighbourhood and many tunnels. Eiji Nakatsu the general manager of technical department of shinkansen got the idea to solve the problem by watching the owls fly. The unique adaptation of Owl feathers is the comb-like leading edge of the primary wing feathers referred to as “fimbriae”. When any bird with normal feathers fly air rushes over the surface of the wing, creating turbulence, which makes a gushing noise. With an Owl’s wing, the comb-like feather edge breaks down the turbulence into little groups called micro-turbulences. This unique feature is helpful in muffling the sound of the air rushing over the wing surface and that is how the Owl can fly silently.

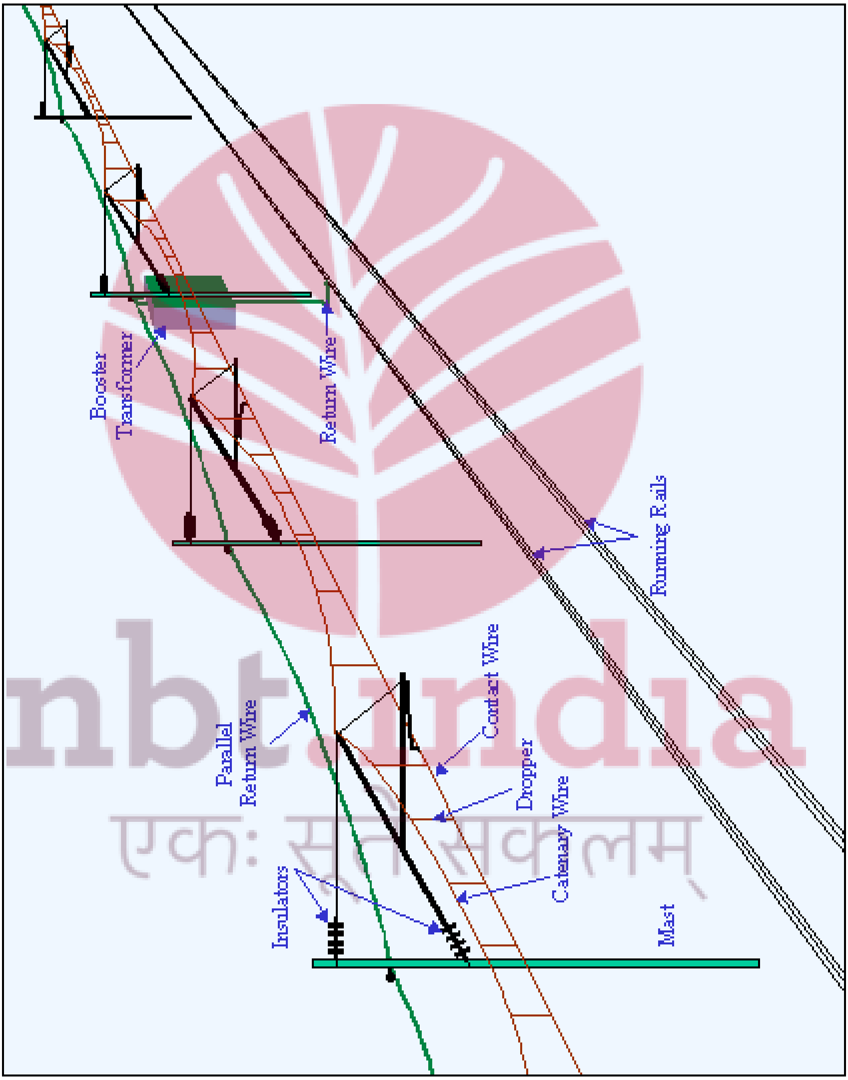

Fig. 3.12: Traction system overview. Source: railway-technical.com

Silent flight gives Owls the ability to capture prey by stealth, and also allows the Owl to use its hearing to locate potential prey.

Fig. 3.13: Feathers of Owl showing comb like structure

Eiji Nakatsu formed a team to test prototypes mimicking these forms. In 1994 a new wing graph based on the design of owl feathers was developed and it replaced the traditional pantograph and was successful in allowing the train to run at 320 km per hour and meet the stringent 70dBa noise standard.

Rolling stocks are generally referred as the vehicles that move on railway. There are different types of rolling stocks being used for High Speed train operation.

When we think of high speed rolling stocks its streamlined shape and nose immediately comes to the mind. There is another interesting story behind the design of these shapes. High speed train operation inside the tunnel was generating atmospheric waves that reached the tunnel exit at the speed of sound. The train was forcing the air out in form of low frequency waves that produced a large boom and aerodynamic variations. Perforated shades were designed at the exit of tunnels to reduce the air pressure and there by sonic boom. However that was not enough and it was considered necessary to reduce the cross sectional area of the train and redesign its nose. The problem basically was the sudden change in air resistance, from open sky to closed tunnel. Again the idea came from watching the kingfisher bird dive at high speed from air to the 800 times denser medium water with barely a splash. The Japanese railway team analysed the body of kingfisher and predicted that the rotational parabolic body was the key feature. Both upper and lower beaks of bird had regular cross sections with the sides of the triangles being curved. Together they formed squashed diamond shape. Various prototypes were tested and it was concluded that kingfisher shape was the best and rolling stocks were modeled accordingly. The new shinkansen 500 had 30 % less air resistance and thus better energy efficiency.

Fig. 3.14: Kingfisher dive

Rolling stocks are broadly differentiated on the basis of power concentration or power distribution. In the power concentration system power units are at the end of train sets and intermediate cars have no traction system.

This system has the following advantages:

- Cost of setting of intermediate cars is less.
- Intermediate cars can be maintained with less manpower
- Less vibration and noise.
- Absence of traction system provides flexibility in train set design so that it can be easily increased or decreased.
- Changing of locomotives makes interoperation very easy.

This system has the following disadvantages:

- Axle load on Power cars become very heavy and thus construction and maintenance cost of tracks increases.
- As there are fewer traction axles, so the acceleration and deceleration is less.
- Energy consumption is higher as there is no regenerative braking.
- Wear and tear of brake shoe will increase.

The power distribution system is composed of many power units. Generally one unit composes of two or three cars and power is distributed by traction and control system. The power distribution system has the following advantages.

- As there are more traction axles so higher acceleration and deceleration function can be performed.
- Axle loads of traction cars are less, consequently the construction and maintenance cost of tracks is less.
- Regenerating braking system makes the system energy efficient.
- Redundancy is high. Even if some power units become defective, train may remain in operation.

Following are the disadvantages of this system.

- Manufacturing costs is higher
- Manpower requirement for maintenance is higher.
- Noises and vibrations inside the cars is greater.

Japanese high speed railway uses the power distribution system and many European countries use Power concentration system. Recent trends indicate shift towards power distribution system.

The rolling stocks can also be broadly classified on the basis of articulation.

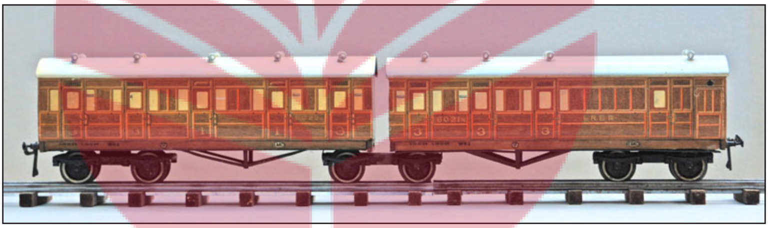

Figure: Articulated Train set. Source: dutchhrca.nl

Articulated trains have car bodies that are connected directly by one bogie with no coupling and thus slide vibration does not occur. Such trains can travel at high speed on sharp curves as bogies are set on the car end and it is possible to decrease deck space for noise interception. Space efficiency for passengers is more in such cases and noise inside a car can be decreased. However articulated train sets cannot be decoupled by each car and need more maintenance works. With few bogies and axles which support car weight, it is needed to decrease car weight accordingly car length of each coach should be shortened. With few axles power of a train sets get limited. French railway uses this type of train sets.

The other type is Non articulated train sets. Non articulated train set means that each of the cars of the train set is on two bogies. In comparison to articulated train set, it permits a full length of the intermediate cars (around 25m). On Indian high speed rail system non articulated train sets should be designed as there may be curves with large radius and car length is more thus passengers can have a feeling of openness. Japanese and German Railways have adopted these train sets.

Apart from articulation other important design considerations for rolling stock are as under.

Car width and carrying capacity: The Track gauge and rolling stock dimensions used in various railways is tabulated below.

Area	Track gauge (mm)	Car width (mm)	Car height (mm)
India	1676	3250	4140
Japan (Shinkansen)	1435	3400	4500
Japan (conventional lines)	1067	3000	4100
Europe	1435	3150	4280
East Asia	1435	3400	4500
Spain and Portugal	1668	3274	4300

To maximize transport capacity under Indian conditions it will be appropriate to adopt cars with maximum dimension so Shinkansen type cars with 3400 mm width may be suitable, however the choice will depend on various techno-economic factors.

Seating arrangement is also significant. For commuter service, six seats per row may be considered as is the case with E1 and E4 services of JR East. Five seats per row will be more comfortable for long distance journeys as has been provided in many high speed trains like CRH3 etc.

Fig. 3.15: 6 Seats per row E1 type Shinkansen

The important features of various rolling stocks of high speed trains is summarized below.

1. **Train length** : Maximum optimum train length is 400 mts. Mixed operation of long single sets and coupled short train sets already exist, e.g. 400 m 1CE1 and 2×200 m ICE2 in Germany, or 400m CRH2 and 2×200m CRH2 in China.
2. **Car length**: The basic car length on articulated High Speed train is about 13-19 meters. Cars on non articulated trains measure about 25 meters**. Articulated cars** are rail vehicles which consist of a number of cars which are semi – permanently attached to each other and share common **Jacobs Bogies**. Instead of being underneath a piece of rolling stock, Jacobs bogies are placed between two car body sections. The weight of each car is spread on one half of the Jacobs bogie.
3. **Crush worthiness**: The High Speed rolling stock should be built in a way that ensures there is a crush proof survival zone

that prevents loss of life to passengers and driver in case of any accident.

4. **Fire safety**: High Speed Rolling Stock should have the highest level of fire safety. The material used should be non flammable, light weight & environment friendly.
5. **Cross wing resistance**: The risks of overturning due to cross winds must be factored into the design equation of high speed trains as the operational conditions in high speed trains generate cross wind resistance.
6. **Reduced Energy consumption & CO_2 emission**: The reduction in CO_2 emission & energy consumption may be achieved by reduction of energy loss from power unit, use of regenerative braking and reduction of running resistance.
7. **Aerodynamic resistance**: Aerodynamics is a key issue for high speed trains. Streamlined body of high speed trains is very significant to make them aerodynamically efficient. Reducing the loading gauge helps reduce aerodynamic resistance, smoother body shape, i.e. flat window, flat door, covered gap between cars, aerodynamic protuberances, covered protuberance as, flat under covers etc. also help reduce resistance. The nose shape of these trains is to minimize air resistance and pressure changes when the train runs into a tunnel. The nose shape at rear end is helpful to prevent rolling. This design also reduces running noise. Longer noses have a limited impact on aerodynamic resistance given that resistance is mainly from the body surface and so body surface is also made as smooth as possible.
8. **Tunnel micro – pressure waves:** When the high speed trains run through a large number of tunnels, the issue of micro pressure waves become critical. Lengthening the nose, optimising the nose shape and having a smaller loading gauge mitigate micro pressure waves.
9. **Body and bogie structure:** Most current high Speed rolling stocks are made of aluminum alloy, steel and stainless steel. As the aluminum alloys are lighter in weight thus the car body

weight is reduced and speed potential of the train increases. Aluminum alloy has other advantages like mechanical strength, corrosion and vibration resistance etc. these have become the preferred material.Newer materials like carbon composite and Aluminum honeycombs are also used as structural components. Bogie structure should the simple and higher and a large number of sensors can be placed on the bogie.

10. **Power and braking system:** The most commonly used power system is AC motors including induction motors and synchronous motors. Regenerative braking is essential to reduce energy consumption.
11. **On board train control and information systems:** High Speed trains should be installed with on board control and information systems which control monitor, diagnose and display the status of the train and its components. The interface between the system and components should be unified for the system integration.

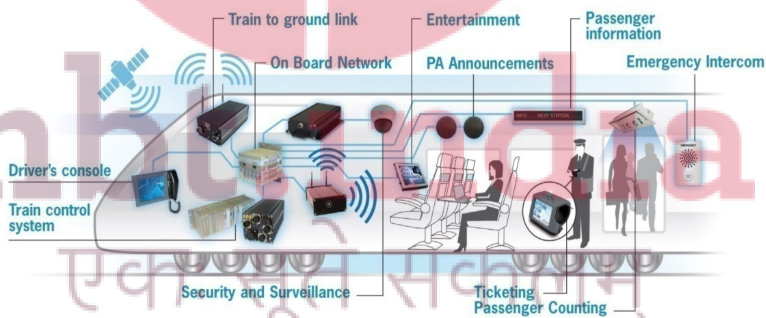

Fig. 3.16: On board system of high speed rolling stock.
Source: eurotech.com

Operating and Signaling system

The main purpose of a signal system is to enforce a safe separation between trains and to stop or slow trains in advance of a restrictive situations. The basic signaling principles for high speed operation are as under:

1. There should be no line side signals as the observation of line side signals becomes difficult at speed above 200 km/h, and more over the stopping distance increases as the speed increases.
2. Cab signalling must be available. Cab signalling is a railway safety system that communicates track status information to the crew compartment of a locomotive or rail car, where the train driver can see the information continuously.
3. Track to train transmission of signalling information must be continuously available in cab in the form of continuous pre-set speed accompanied with braking sections by indication of target speed and target distance.
4. The main cab signalling must be associated with a speed check and application of automatic brake whenever the actual speed exceeds the set speed limit.

These principles can be ensured by adopting following systems.

1. **Automatic control of train spacing:** The spacing of trains is ensured on the basis of line being divided into sections where entry into a section under normal running conditions is blocked when it is occupied. The signaling system must be capable of providing the cab tactile unit with information commanding them to stop before entrances to a section constituting stop point.
2. **Protection from unexpected obstacles:** High speed trains must be equipped with ground/train communication line. Station or traffic controllers should also be capable of commanding the immediate stopping of trains.

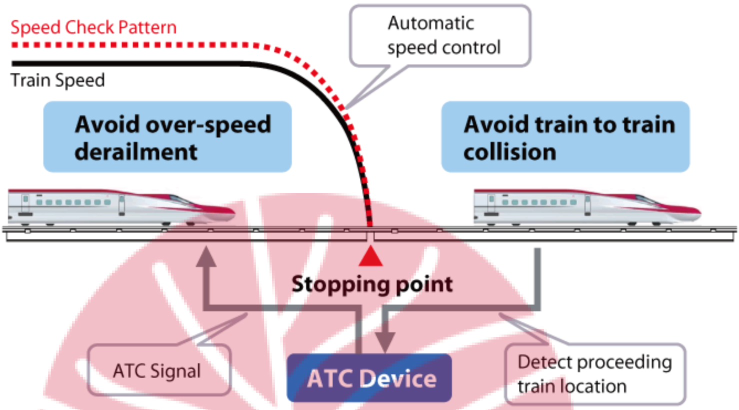

Fig. 3.17: Automatic train control. Source: jchighspeedrail.com

3. **Indication of speed limits in cab:** The signaling system of high speed train should be able to provide in the cab various speed limits like permanent speed restrictions. Temporary speed restrictions etc.
4. **Control of speed:** When speed limit is exceeded, particularly during braking period, the emergency braking should be activated.

Fig. 3.18: Cab signaling. Source: networkrail.co.uk

Signaling system on shinkansen system(Japan)

Shinkansen system employs Automatic train Control System. It uses a comprehensive system of Automatic train protection. Centralized traffic control manages all train operations, and all tasks relating to train movement, track, and station and time schedule are networked and computerized. The operating conditions of onboard devices are transmitted by mass transmission system. This allows driver to ascertain conditions of the car door, air conditioning devices etc. from his desk. **COSMOS,** The Computerized Safety Maintenance and Operation System of Shinkansen is a highly integrated next generation system that performs transport planning and management on a real time basis.

Fig. 3.19: Traffic control system of Shinkansen. Source: hitachi.com

Signaling of TGV system of France

Transmission Voie-Machine (TVM) which literally means track-to-train transmission is a form of cab signaling for use on high-speed railway lines. This system was first deployed in France as TVM-300 followed by TVM-430.

At speeds of above 220 kilometers per hour, TGV trains run only on dedicated tracks designated as *lignes à grande vitesse* (LGV). **At high-speeds it is not possible for a driver to accurately see colour-light based railway signals along the track-side. Signaling information is instead transmitted to the train and displayed as part of the train controls. The driver is shown the safe operating speed, displayed in kilometers per hour.**

TVM-430 system transmits more information than traditional signaling would allow, including gradient profiles and information about the state of signaling blocks further ahead. This high degree of automation does *not* **remove the train from driver control, although there are safeguards that can safely bring the train to a stop in the event of driver error.** Dashboard instruments show the maximum permitted speed for train's current block and target speed based on the profile of the line ahead.

ERTMS

The European Railway Traffic Management System (ERTMS) is a project developed by eight agencies namely Alstom Transport, Ansaldo STS, AZD Praha, Bombardier Transportation, CAF, Mermec, Siemens Mobility and Thales. ERTMS has two basic components

- ETCS, the European Train Control System, is an automatic train protection system (ATP) to replace the existing national ATP-systems;
- GSM-R, a radio system for providing voice and data communication between the track and the train, based on standard GSM using frequencies specifically reserved for rail application with certain specific and advanced functions.

ERTMS aims at replacing the different national train control and command systems in Europe.

There are three levels of ERTMS, level one uses track side signals, level two uses fixed block authority and level three the most advance one uses moving block authority. The last two levels are relevant for high speed rail systems.

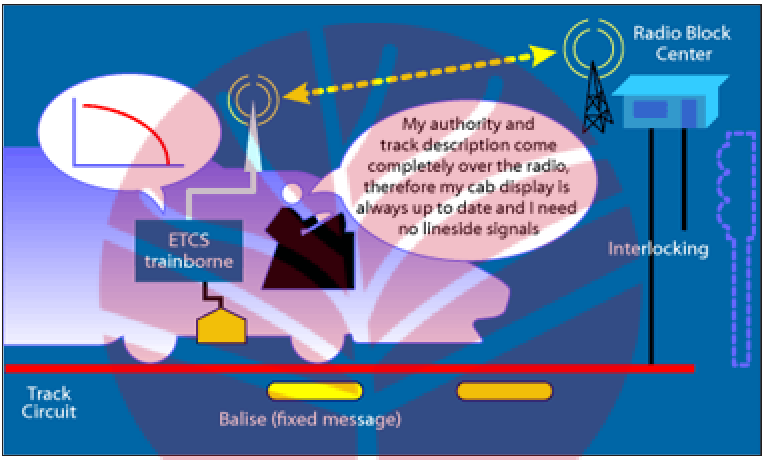

Fig. 3.20: ERTMS level 2. Source: ERTMS website

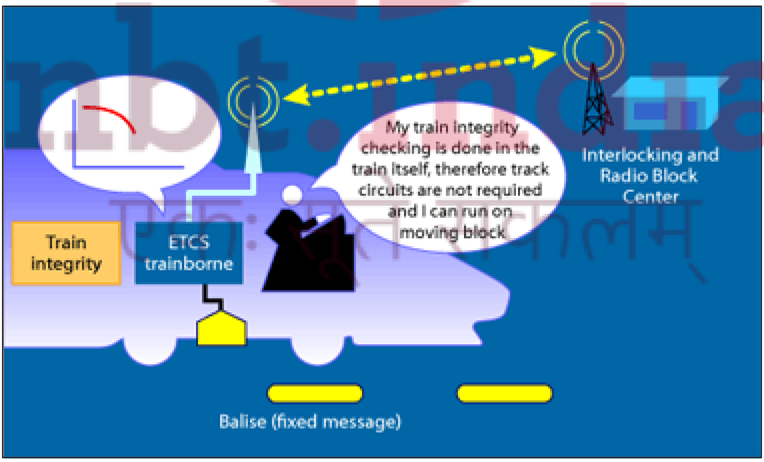

Fig. 3.21: ERTMS level 3. Source: ERTMS website

Telecommunication features for high speed train should be very efficient. Communication link between various stations, control centres, power stations, train depots etc. is very important for high speed train operation.

Synchronous Digital Hierarchy (**SDH**) is the standardized protocol to transfer multiple digital bit streams synchronously over optical fiber using lasers or highly coherent light from light-emitting diodes. The main transmission route is made of optical fiber cable. Train radio system should have the reliability of highest standard. The transmission quality of better than 99.9% should be provided. This can be ensured by use of Leaky Coaxial Cable(LCX). This system consists of a coaxial cable run along tunnels which emits and receives radio waves, functioning as an extended antenna. The cable is "leaky" in that it has gaps in its outer conductor to allow the radio signal to leak into or out of the cable along its entire length. Because of this leakage of signal, line amplifiers are required to be inserted at regular intervals, typically every 350 to 500 metres, to boost the signal back up to acceptable levels. The signal is usually picked up by portable transceivers carried by personnel. Transmissions from the transceivers are picked up by the feeder and carried to other parts of the tunnel, allowing two-way radio communication throughout the tunnel system.

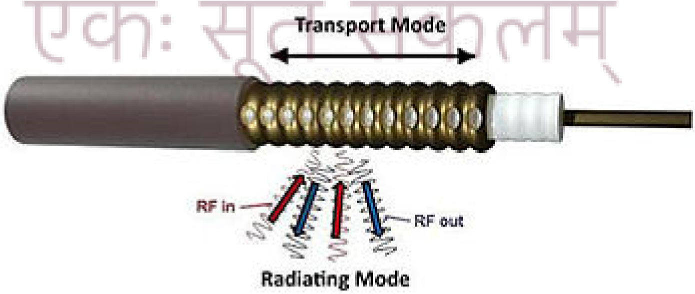

Fig. 3.22: Leaky Coaxial cable used for Train radio communication.

There should be auxiliary system for detection of falling and dragged objects and cross wind detectors should also be present.

Operational Features of Bullet trains

Bullet train operation has to be safe, reliable and punctual. It should provide maximum passenger convenience and comfort. Moreover it should have enough capacity to meet the traffic requirements. Conventional trains generally have one locomotive in front to provide power to carry along number of attached vehicles. The other type of train sets are called EMU(Electric Multiple Unit) as they have many small power units distributed in several vehicles of the train. These trains have high acceleration and breaking capability. Turnaround at terminals is very easy for these trains as locomotive changing is eliminated and there is no need for shunting as the driver changes the cab and starts driving in reverse direction. Due to these features these trains are suited for high frequency operation in suburban areas. High speed trains of Japan are mainly of this type.

The high speed train operation should be highly efficient as the cost associated with high speed rail infrastructure is very high and there should be best possible use of tracks, power system, rolling stock, manpower etc. High speed train operation should be carried out in such a manner that transport efficiency is maximum.

Planning for high speed rail operation starts with a fairly accurate ridership forecast. To begin with, assessment is made as to the number of commuters coming to different stations and their mode of accessing the high speed rail stations. Once the origin of travel is finalized then the details of their destination is obtained and a origin destination matrix is prepared. From this "origin and destination matrix" one can calculate the numbers for each station, each direction and during each hour. The ridership forecast provide the following set of data which is the starting point for operational planning: a) Passengers boarding trains in each direction; b) passengers alighting from trains in each direction; and c) passengers riding on trains between stations for each direction.

The next step of operational planning is to decide the time table. In order to make a train timetable the running time between the stations is calculated. This calculation is based on parameters, such as the inter- station distances, range of operational speed, acceleration and brake performance of rolling stocks, signaling system, grade of a track, degree of curves, the train set length, etc.

Train frequency is planned on the basis of the cross-sectional demand and the time distribution of the demand for convenience and comfort of passengers. To find out the train frequency, the maximum cross-sectional demand per direction is divided by the number of seats of a train. The maximum train per day when divided by revenue operation hours gives the average number of trains per hour.

This is based on the assumption that every train carries 100% seated passengers. This is not the case so at initial stage a load factor of 65-70% is taken for these calculations. The average train number per hour needs to be judiciously distributed keeping in mind the passenger distribution during peak and non peak time.

Another operational concept in this connection is the headway which is the name given to the elapsed time between trains passing a fixed point in the same direction over the same track. The headway is dependent on factors like signaling system and the time taken for the reversal of trains at terminals.

One aspect of this planning is the optimum utilization of rolling stocks. Operational planning should ensure that train set utilization is optimum i.e. maximum number of train sets are available for passenger services and at the same time maintenance cycle of train sets should not suffer. To ensure this a train set utilization path is prepared which shows a list of trains that will be operated consecutively for one day.

Another important operational planning aspect is the planning for train crew duty. These include preparation of crew roster, working hours for a day, continuing hours for actually driving the train, time interval between the trains and attendance and leaving time, etc.

Stations and terminals should be carefully designed to get the maximum out of high speed rail projects. The plan for new high speed rail lines should be optimally integrated with the city features so that access time is minimized. Parking lots, vehicular flow, boarding procedure, ticketing system should be commuter friendly. Interchange with other modes of transport should be smooth. Property development in the form of real estate and commercial centers may be innovatively done to generate constant revenue stream.

The technological details provided in the chapter must have made the concept of High Speed Trains very clear. The technology is different from the conventional rail technology and there are many variants of the technology and depending upon the conditions the appropriate technology may be adopted. Once we have understood the bullet train technology it is necessary to examine the benefits and criticisms in greater detail.

4

Good or Bad Debate

Benefits and Criticism

Society gets immense benefits from Transport system as these systems provide access and mobility which are very much essential for Socio economic growth. Public transportation is a crucial part of the solution to any nation's economic, energy, and environmental challenges and thus helping to bring a better quality of life. In increasing numbers, people are using public transportation and local communities are expanding public transit services. Every segment of society be it individuals, families, communities, and businesses benefit from public transportation. Some of the important benefits of public transport system is explained below.

Benefits of public transport.

Social

- Public transport system inculcates a sense of togetherness among the fellow travellers and thus helps foster a sense of community. For example, people travelling together in a train compartment or bus are more likely to have a community feeling than those travelling in personal vehicles.
- Every section of the society get access to public transport improving their mobility without any discrimination of income, sex, age etc.

- Public transport encourages people to adopt a more active healthy lifestyle, by motivating them to walk or cycle as a means of last mile connectivity.
- Road accidents are a major cause of human fatalities worldwide. Use of public transport helps reduce injuries and fatalities as it takes many private vehicles off the road.
- Public transport puts less strain on individuals. Driving on busy roads can be quite stressful as one need to be very attentive; similarly waiting at busy traffic signals may be quite unnerving. Search for appropriate parking place can also be a harrowing experience. Public transport passengers on the other hand need not have such worries and can relax and listen to music, play computer games or read a book while travelling and have a good time generally during travel.

Economic

- Energy resources are dwindling at a very fast pace, in such a scenario private vehicles may place considerable drain on the scarce energy resources. Use of public transport reduces reliance on energy resources as public transport modes have improved energy efficiency.
- Private vehicles are still beyond the means for majority of population. Besides maintenance of private vehicle particularly cars can be very expensive. Public transport is affordable to a vast majority of people as it is economical.
- Public transport promotes efficient land use as more people can be transported per unit of land use. The space is optimally utilized and there is more space for housing, recreation centers, greenery etc.

Environmental

- Public transport mitigates harmful emissions and thus reduces air pollution which is a major cause of environmental degradation.

Public transport also reduces road congestion and thereby further enhances the environment quality.

- Public transport is a very energy efficient mode of transport

However, public transport system is facing many challenges today due to increased population, rapid urbanization, scarcity of natural resources, availability and price issues related with Oil and other energy resources. There is growing recognition of the fact that these challenges have to be met in a sustainable way.

The need for more sustainable mode of transport and requirement to meet the new transportation challenges are pushing countries towards the high speed rail systems as high speed Rail system has several environmental, social and economic benefits and thereby makes the transportation system efficient, effective and sustainable.

Benefits of High Speed Rail system

Environmental benefits

When compared with other modes of public transport the high speed rail system has lesser impact on climate and environment. To illustrate the environmental benefits of high speed rail system it is necessary to compare and contrast the overall climatic and environmental impact of high speed rail with other competitive transport modes like road transport, air transport etc. The parameters for such a comparison may be like energy consumption and green house gas emissions, air pollutant emission, and environmental damage like land use and resource depletion etc.

Current transport system of the world generates extreme pressure on energy resource and ecosystem as 80% of energy consumption is derived from fossil fuels. Transport sector produces around 23% of worldwide CO_2 emission, thus being the second largest source of manmade CO_2 next only to Electricity & heat generation.

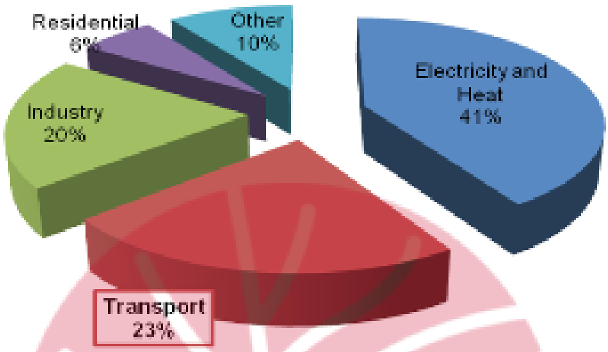

Fig. 4.1: Distribution of CO_2 emissions in the world by activity sector-2007. Source: IEA, 2009

When the emissions from industry & energy sector are falling it is worrisome to note that transport emissions are increasing. In fact in Europe the transport emissions increased by 25% between 1990 & 2010.

Study of Global transport CO_2 emission by mode share indicate that road traffic accounts for 73% of global transport emission. The aviation sector allows for 13% of emission, shipping sector accounts for 9% of emission. By contrast the rail sector accounts for only 2% of emissions.

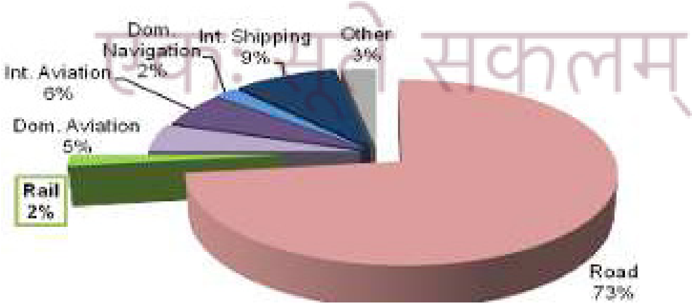

Fig. 4.2: Global transport CO2 emissions by mode share. Source: ITF 2005

Thus it is evident that transport sector is a major source of global emission of CO_2 and amongst transport sector the rail has least emission and thereby use of high speed rail will significantly reduce even these emissions. The above figures are in absolute terms, better indicator of global emissions will be average CO_2 emissions per passenger km.

The study of CO_2 average emission per passenger km in Europe indicates the following:

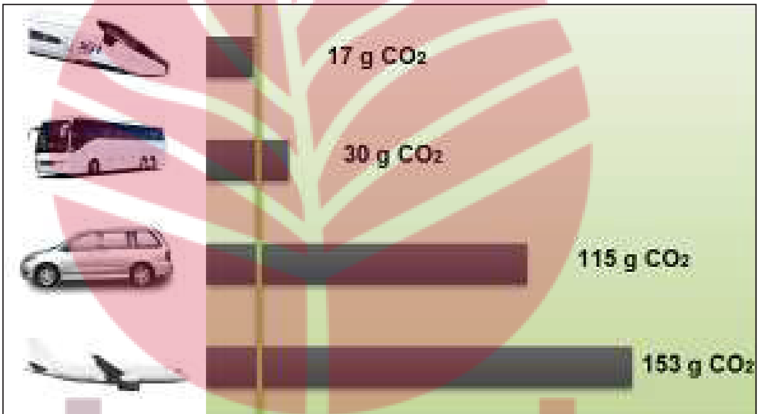

Fig. 4.3: CO2 average emission per passenger km. Source: Alstom & Systra

High speed rail offers the best performance in terms of energy consumption & environmental protection and thus fits in appropriately in the globally adopted primary strategy response of Avoid, Shift and Improve to the challenge of reducing the environmental impact of transport.

High Speed Rail has been found to be the most energy efficient mode of transport and has the lowest carbon foot print. It is getting more attention as it is not the part of problem but is a part of the solution. Most of the developed high speed rail systems are based on electricity and thereby also has minimal impact on environment.. The Environmental benefits of high speed rail can be best understood by the example of Paris – Marseille Route the details of which is presented in Figure 4.4:

High Speed Rail networks have set up many mile stones in the field of energy efficiency. Shinkansen 500HSR train has achieved a mean value of 0.029 KWH per seat km mainly due to their lower mass and higher seating capacity. Swedish Rail has taken the step to purchase 100% renewable energy from hydroelectric and wind powered sources. A high speed train between Stockholm and Gothenburg can carry up to 300 passengers and emits only 400 gm of CO_2 per passenger, compared to an average car which would emit an average of 44.5 kg CO_2 per passenger.

Critics of High speed rail mention that energy consumption of trains increase exponentially with speed, mainly due to increase in dynamic air resistance, and thus it is argued that the energy requirement to power a high speed train is much greater than that needed for trains running at conventional speed. However if energy use per passenger kilometer is compared, then HSR trains can be just as energy efficient as, or even better than conventional trains.

The most important reason that can make HSR a more energy efficient means of transport than conventional trains is the higher capacity utilization which is also known as load factor. This may be defined as the number of passenger kilometers travelled as a percentage of the total seat kilometers available. With a good load factor, the energy consumption per passenger for high speed trains can be smaller than that achieved on conventional trains.

Moreover as speeds are higher and passengers can reach their destination in a short time the actual energy per passenger is still relatively low. One more important aspect relevant from energy consumption point of view is the relative energy use by auxiliary services of the train like compressors, ventilators, heating, air conditioning, lighting, etc. Energy consumption from these

Paris – Marseille corridor		Aircraft	Car	HSR
				
Basic facts	Commercial distance (km)	634	769	750
	Vehicle consumption	4038 L / flight	49 koe	17.3 Mwh
	Average number of passenger per vehicle	122	2	400
	Number of seat per vehicle	150	4	516
	Load factor (%)	80	50	77.5
Consumption and CO2 emissions *Primary energy equivalent*	Consumption (toe) *Primary energy equivalent*	3.9	0.1	3.8
	CO2 emission (kg) *Primary energy equivalent*	11823	179	692
	Energy efficiency *goe (primary) / pass.km*	51	37	13
	Consumption *Koe (primary) / passenger*	32.2	28.8	9.6
	Environmental efficiency *kg CO2 / passenger*	97	89	2

Fig. 4.4: Environmental benefits of HSR. Source: ADEME (French Environment & Energy Efficiency Agency

services is less in case of high speed rails as these trains have less operating time and thus consumption per kilometer is less.

Air Pollution Mitigation By HSR Network:

Introduction of harmful particulates and other matters in the atmosphere through various transportation systems is a cause of concern as it causes serious harm to flora and fauna of the world. According to the 2014 WHO report, air pollution in 2012 was the cause of death of around 7 million people worldwide.

Carbon monoxide, hydrocarbons and nitrogen oxides are major air pollutants and over 50% of the harmful emissions of these air pollutants is contributed by petrol and diesel engines.

Model comparison of various modes of transport indicates that there is very less air pollutant emitted by High Speed Rail System. The data produced below will prove the above claim.

Characteristics and components (unit per person travelling) Effects	Aircraft	Car	High Speed Rail
Duration (h:m)	02:30	04:14	03:37
Energy Resource Consumption (converted into litre of petrol)	32.8	38.6	11.1
Carbon Dioxide (Kg) *Greenhouse gas, Global Warming*	77.1	86.0	19.2
Particulate matter (g) *Human Toxicity*	2.1	21.2	1.0
Sulphur Dioxide (g) *Acidification*	43.4	3.2	19.5
Nitrogen Oxides (gm) *Acidification, Nitrification, Summer, Smog/Ozone*	268.3	223	17.2
Non-methan hydrocarbons (g) *Summer smong/ozone*	20.8	18.3	1.1

Table 1: Model comparison of air pollutant emissions on Frankfurt – Hamburg HSR section. Source: IFEU 2008

The above illustration may be an eye opener; it shows that high speed rail is by far the best mode of transport when it comes to air pollution mitigation parameters. Thus high speed rail system can be very useful in reduction of air pollution and its associated ill effects.

Noise Pollution and Vibration Effects of HSR

All medium of transport generate some amount of noise and vibration and these may have deleterious impact on mental and physical health of living beings. Noise pollution may have serious cardiovascular effect in humans, a rise in blood pressure, and an increase in stress and narrowing of blood vessels, tinnitus, hearing loss, sleep disturbances, and other harmful effects including an increased incidence of coronary artery disease. Noise pollution also adversely affect the animal life in many ways such as interference with their reproduction and navigation. Thus noise pollution and vibration effects of each mode of transport must be examined in detail.

It has been reported in many studies that when compared with other modes of transport the noise generated from running of trains is least disturbing to the population. European Working Group on Health and Socio-Economic Aspects in one of its studies concluded that to disturb 10% of citizens highly a maximum railway noise level of 70 decibels is needed, while for the road traffic this effect is reached at a level of 58 decibel and for air traffic this figure is 54 decibel.

Noise effects associated with High Speed Rail can be traction noise, rolling noise, concrete structure noise, aero dynamic noise, pantograph noise, sparks noise etc. Aerodynamic noise is the most dominant noise at speeds in excess of 220 km/h. Proper design of train set including its pantographs, erection of noise barriers etc. help in reduction of aerodynamic noise.

Vibration generated by high speed rail system is effectively managed by appropriate suspension system and use of under ballast mats, resilient tie pads etc. Japan took the lead in managing the impacts of noise and vibration and through continuous monitoring and improvement the Japanese high speed trains do not create any serious noise pollution and vibration impacts.

Resource Efficiency of High Speed Rail System

The burgeoning world population is putting considerable pressure on global natural resources. On one hand the population is growing and on the other hand resources are depleting. Thus it is of paramount importance to have a sustainable transport system, which will optimally use the natural resources. Resources if not used optimally may aggravate energy crisis and retard the socio economic development.

Transport like any other development activity leads to depletion of resources, however high speed rail sector has greater resource efficiency. High speed rail sector emphasizes on minimizing emission from construction of new rail infrastructure, it also uses low carbon material which are recyclable. High speed rail technology uses light weight construction material e.g. aluminum, similarly weight reduction is also achieved through articulated train designs which have reduced number of bogies. Overall weight reduction and use of insulating materials helps in improved resource use efficiency.

Modernization and refurbishing of existing rolling stock throughout the life cycle helps in reduction of carbon foot print and improvement of resource use efficiency. For example In German Railways, 59 first generation Inter City Express trains were completely rebuilt between 2005 and 2008. According to reports, this act lead to great reductions in the use of resources compared to the purchase of new trains, saving roughly 16,000 tons of steel and 1,200 tons of copper. Moreover, refurbishing the components, rather than using new manufactured ones, reduced

CO_2 emissions by 35,000 tons. High speed rail offers several advantages to limit the extensive use of raw materials.

The Table given below shows how efficiently a ton of resource used to produce a high speed rail vehicle (TGV duplex) is able to offer forty times more seat Km during its whole life compared to any average car, assuming similar recycling rates for all vehicles.

Mode	Mass (t)	Seats	Km/ year	Life time (year)	Seat.km / tonne used
HSR (TGV Duplex)	400	516	49000	30	19160
Average car	1.2	4	15000	10	48000

Table 2: Comparison between the French TGV and an average Car. Source:Calculation by SYSTRA.

The longer life cycle of rolling stock of high speed rail contributes in improved resource use efficiency. High Speed Rail projects adopt precise landscape integration policy. Some of the adopted measures are regeneration and planting of vegetation and other landscaping works.

The amount of land used by any transport infrastructure determines the impact on biodiversity and natural habitat and is thus a very sensitive indicator of its environmental impact. High Speed Rail network also uses minimum land per unit as compared to other works of transport. High Speed Railways have a lower requirement of land take per unit (i.e. passenger-Km) as can be seen in next page.

Thus it is amply clear that high speed rail have immense environment benefits and with the growing concern for environment this mode of transport is occupying center stage. Apart from its environmental benefits high speed rail offers various advantages for public such as reliability, punctuality, comfort, time savings, access for all, the ability to work during

Fig. 4.5: Land-take by roads and rail, source UIC 2008

travel, direct travelling from city centre to city centre and last, but not least, excellent safety record. Now let us examine the Social impacts of high speed rail networks.

Social Impacts of High Speed Rail Networks

Quality and Productive Time:

The world is changing fast and everyone is hard pressed for quality time and opportunities to relax. When travelling on high speed rail, people get time to do things they could not do if using land or air transport. High speed rail has genuine advantage in terms of having large amount of uninterrupted time as waiting, security check time, baggage collection time etc. is minimal.

Reliability and comfort

Every traveler considers the reliability of any public transport mode so that they may plan their schedule in a judicious manner. High speed rail system is one of the most reliable transport systems of the world as their punctuality standard is very high. The high standard of punctuality helps in improving the headway i.e. the gap between two consecutive rail services and there by increases the capacity. The trains running as per advertised time table makes it a very attractive mode of transport as people value their time and are interested in productive use of time.

High speed rail travel is not only reliable but highly comfortable also. Reserved seats give the passengers their own space and as there are very few stoppages so the journeys are less interrupted. High speed trains have ample space to walk which enhances the quality of travel experience. High speed trains score better on all important indicators of comfort like mobility within coaches, distance between seats, services on board, potential impacts on health during travel time, exposure to noise disturbances onboard being some of them.

Social Mobility and Integration

High speed rail network provides the much needed connection between various political and economic centers of any country. This linkage creates many opportunities for social mixing. Development of high speed rail network leads to development of overall public transport infrastructure. Regional train services, feeder routes etc, gets modernized and thus overall accessibility improves significantly.

Air travel calls for systematic multiple human intervention many times like issue of boarding pass, luggage check in, security checks, luggage collection etc. Use of personal conveyance is limited to those persons who can afford the purchase, operation and maintenance of personal vehicles. High speed rail travel encourages people to travel without much assistance and thus it improves the mobility of all sections of society like elderly people and persons with disability. As the population is ageing and attitude towards persons with disability is changing, increasing need is being felt for improving the accessibility of public transport for the differently abled and the aged.

Many rail companies run specific programs to improve the accessibility and mobility of public. Acces plus is special assistance service offered by French railway SNCF to persons with disability. Acces plus service is available in nearly 360 stations throughout the French national network and helps the persons with disability to plan journey and provides a companion to meet such persons at arrival and destination stations to offer all necessary assistance. German railway DB's Mobility service centre offers similar services to passengers with restricted mobility. Spanish railway provides ATENDO service in the form of free assistance to railway passengers with reduced mobility or other disabilities.

It is not only the persons with disability who have the mobility issues but the ageing population also needs to be specially catered to by the public transport systems. The proportion of population 60 years or older was eight percent in 1950 and became ten per cent in 2000 is expected to increase up to twenty one per cent in 2050. This segment of population needs better comfort and high speed rail system provides that in plenty.

The proposed quadrilateral network of high speed rail network will connect important social and economic centers of India and thus will have immense impact as far as socio cultural integration and economic opportunities are concerned. It is very appropriate that Mumbai–Ahmedabad section has been chosen to be the first operational high speed rail system of India as faster connectivity between these two very important financial and cultural centers of India will generate many positive externalities. As of now express train journey takes around six hours to cover the distance which will come down to less than two hours. All the regional transport connections will also improve leading to faster social mobility and accessibility thus making the region very attractive for investments etc.

Similarly when the proposed golden quadrilateral of high speed rail network will be operational then India will achieve very high order of social mobility and greater accessibility. Diamond quadrilateral of high speed rail network in India will bring a socio-economic revolution which will change not only the face of India but will alter the mode of living of the Indian people in a very positive way. From living in hundred kilometers per hour age to a three hundred kilometer per hour age, people's outlook to life also changes.

Economic Benefits of high Speed Rail Networks

Economic development is not merely limited to Gross domestic product indicators. In economic calculations externalities like cost or benefits not transmitted through prices are becoming equally important. High speed rail network bolsters inter regional connectivity, labour mobility, business efficiency and local importance of the region and thereby promotes economic development

High speed rail projects have very high investment cost. Building new high speed rail infrastructure involves three major types of costs e.g. planning and land costs, infrastructure construction cost and superstructure cost. The cost consideration will be inappropriate if we do not take into account the external costs.

Consideration of external cost

External costs related to transport are costs generated by transport users and not paid by them but by society as a whole, such as congestion, air pollution, climate change, accidents, noise but also costs for nature and landscape damage.

The table below indicates who is paying for external costs.

Cost Categories	Who is paying	
	Transport Users	Non Transporters
Climate Change - Natural Hazard - Reduced harvest	Users do not pay	Insurance (covered people) Public authorities Individuals Future generation
Air pollution - Human health - Animal health	Users do not pay	Insurance (covered people) Public authorities Individuals
Accidents - Body injuries - Damages	Partially, through insurance	Insurance (covered people) Public authorities Individuals
Congestion - Stress - Decrease in productivity	Partially through decrease in productivity	Companies Individuals Health Insurance (covered people)
Noise	Users do not pay	Individuals Health Insurance (covered people)

Table 3: Who is paying for external costs? Source: CER 2008

As markets do not include external costs while making cost comparisons of various goods and services so it becomes very difficult to understand the real costs and benefits. This is particularly true with transport sector and thus a misleading price signal is generated and people are forced to take decisions on the basis of such flawed price signals. Thus it makes a case for internalizing all external costs and including them in transport price calculations to create a level playing field. If that is not done then transport activities having negative externalities like road transport will get promoted and society in general will get penalized.

> "The total external costs of transport in the EU plus Norway and Switzerland in 2008 amount to more than € 500 billion, or 4% of the total GDP. About 77% of the costs are caused by passenger transport and 23% by freight. On top of these, the annual congestion cost of road transport delays amount to between € 146 and 243 billion (1 to 2% of the total GDP). Road transport modes have by far the largest share in these costs (93%). This can be explained by the large share of road in the overall transport volume as well as their higher average external costs per passenger-km or tonne-km. Passenger cars have a share of about 61%, followed by trucks (13%), vans (9%), two-wheelers (6%) and buses (4%). From the non-road modes, aviation has the largest share in external costs with about 5%, although only intra-EU flights are included. Rail transport is responsible for less than 2% and inland shipping for only 0.3%."
>
> — Source: CE Delft, Infras, Fraunhofer ISI External Costs of Transport in Europe Update Study for 2008.

Few countries adopt definite measures to account for external costs. Congestion charges are levied in some form in London and Singapore to limit congestion and pollution. However such measures are very limited. "Polluter pays principle" must be adopted at a far wider scale. It is ironical that road sector is the most important contributor to external costs and does not internalize such costs, on the other hand rail sector internalize many of its costs particularly in Europe where it is fully integrated into the EU emissions trading scheme (ETS).

The cost associated with construction, operation and maintenance of high speed rail is the most "legible" cost for society as it hardly generates any "shadow costs" and even if it generates some external cost, it by and large internalizes such costs. These facts should be considered while deciding the public investment for different transport systems. If that is done in a fair and transparent manner then the most sustainable form of transport will flourish.

Balanced Local Development

High Speed Rail networks make significant economic contribution to local development. They trigger beneficial trends in local economies like employment generation, tourism promotion, increased business activities etc. Overall technological development of the city takes place which helps these cities to attract better investments. The overall image of the city gets a boost and the city begins to receive social, technological and institutional support.

A comparison of cities with and without Shinkansen railway stations – 10 years before and after the opening of Shinkansen will press home the point made above.

Sector	Annual growth percentage before opening Shinkansen		Annual growth percentage after opening Shinkansen	
	Cities with a Station	Cities without a Station	Cities with a Station	Cities without a Station
Wholesale	12.9%	20.8%	11.6%	8.7%
Retail	10.1%	13.5%	10.0%	8.6%
Industry	13.7%	14.2%	9.5%	7.8%
Construction	13.8%	14.9%	8.0%	6.4%
Population	2.7%	3.4%	1.9%	1.6%

Table 4: Comparison of cities with and without Shinkansen railway stations – 10 years before and 10 years after the opening of Shinkansen. Source: Brian D. Sards (1993)

Similar pattern has been observed elsewhere in the world. Le Mans, 211 Km from Paris, with 150,000 inhabitants, with a station in the city centre and a journey time of 54 min. is another good example. Before building the station, the town put in place a development plan to control and reorganize the surrounding area. Similarly, Cologne in Germany redeveloped after the introduction of high speed rail network. In Turin, Italy a major redevelopment of the city centre took place around the new high speed rail station. Korea Train Express (KTX) has helped in reduction of north-south imbalance and brought about a shift in economic geography. Yongsan Station has developed various activities like electronic and computer centre, cultural facilities, a shopping and fashion arcade, restaurants, etc.

Green jobs

It is amply clear that high speed rail sector is less polluting, has better resource use efficiency and lesser energy consumption thereby making it a very environmentally proactive sector. General public, entrepreneurs and professionals alike are concerned with environmentally sound economies and it is widely accepted that further job creation should be green and clean. Low carbon economic model will create green employment opportunities. Today's aspiring young generation is interested in green jobs as these jobs will maintain, restore or avoid degradation of environment.

High speed rail sector is a labour intensive sector and it provides environmentally sound jobs. Investment in high speed rail projects generates employment during the whole life cycle of infrastructure. Studies show that ten new rail jobs generate fourteen new indirect and induced jobs, whereas in the road sector, creating ten direct jobs will create only five indirect and induced jobs. The international experience indicates that high speed rail sector creates large number of jobs. Construction of LGV East in France created around 63000 jobs. Similarly the Madrid-Valencia high speed rail line created more than 100,000 direct jobs during the construction period from 2004-2010. High speed rail also generates permanent jobs in its operation and maintenance phase as well.

It is also pertinent to point out that most of the high speed rail companies are signatories of UIC Declaration on Sustainable Mobility and Transport. These companies strive to

- Deliver a transport mode with a strong sense of responsibility
- Raise the levels of customer satisfaction through meeting the needs and expectations of the end-users
- Become an increasingly preferred transportation mode
- Improve safety, reliability, punctuality, cleanliness, comfort, and environmental advantage
- Enhance technological innovation
- Conduct joint research into the best practices and procedures
- Contribute towards national and global reductions of CO_2 emissions
- Provide opportunities for modal shift from other transport modes
- Increase the energy efficiency of the railways
- Reduce the noise and other impacts - not only from railway operation, but also from all facilities including; stations, factories, back offices, and other activities.

Thus it is evident that High Speed Rail Networks bring a plethora of benefits for the city, region and nation. High speed rail networks are by far the most environment friendly mode of transport and it has far reaching social benefits in the form of regional development and national integration. Once the external costs are internalized, we may find that High Speed Rail networks become economically competitive as well. However, it is also appropriate to examine dispassionately the various criticisms brought against high speed rail network.

Criticism of High Speed Rail Network

"If they succeed, they will give an unnatural impetus to society, destroy all relations which exist between man and man, overthrow all mercantile regulations, overturn the metropolitan markets, drain the provinces of all their resources and create at the peril of life, all sort of confusion and distress." This is not about bullet trains but about railway projects itself as reported in a widely circulated English newspaper *John Bull* in 1835. The world is full of doubting thomases who voice gloomy forebodings about every new farsighted projects. Similarly bullet trains projects have not been spared and has invited may criticisms.

The first and the most important criticism is the huge cost associated with the construction, operation and maintenance of high speed rails and the whole process is very cumbersome. Terming it as wasteful spending in the name of social cause, they argue that such trains in China are priced beyond average citizen's budget.

In France and likewise in Japan, there is only one high speed rail line that is profitable. And in USA, the high speed rail has not made much progress. Hence, spending billions on high-speed rail will mostly serve affluent travelers and it will require government support forever. Moreover, the technology itself is outdated and has not proved transformational. Often, comparisons of high speed rail with air transport is made, with many of the view that many airports can be built with the same kind of money and similarly many air services can be started.

Whenever any big project is contemplated it is always a difficult choice because of their scale and impact as they involve tradeoffs, imperfections, pros and cons. Such projects are generally undervalued and over criticized during early stages as it is easy to point out inconveniences but difficult to fully comprehend the eventual benefits. What is needed is full commitment by all stakeholders and completion of the project in a mission mode. In the next chapter let us try to understand wherefrom the money will come for the project.

5

Where is the Money?

High Speed Rail projects have very long gestation periods. These projects are also very vulnerable to changes in social, political and economic environment, which may severely impact the progress of the project.

Various risks associated with High Speed Rail projects have a direct bearing on its financing. The risks associated with high speed projects are of following types:

Market risk: Many market conditions are assumed while arriving at the viability of these projects. Various demand projections like passenger volume etc. is made but if these projections are not fulfilled then the investors will suffer.

Operational risk: This is related to technical performance of the project during its operational phase. For example, if it is not possible to run the trains at a desired frequency then the performance may fall below the projected level. However these risks can be overcome by entrusting the project to reputed contractors and get suitable insurance.

Interest rate risk: During the long life cycle of high speed rail projects, interest rate varies and this may have very significant bearing on these projects as the capital investment is very high and payback periods are also very long. Passing on these risks to consumers through increase in tariffs may not be possible in many cases.

Foreign exchange risks: These risks are more pertinent in case of such high speed rail projects which rely on foreign financing while their tariffs are fixed in domestic currency.

Construction risk: During the construction of high speed rail projects some unexpected event may take place leading to cost and time overruns. These risks cannot be totally eliminated but can only be mitigated.

Regulatory risk: High speed rail projects have to interface with various regulatory authorities like tariff authorities, environmental regulators etc. These authorities may take some action which may adversely impact the project. Financing agencies expect a transparent and fair regulatory system backed with sound legal system.

Political risk: This risk is outcome of any political action changing the course of the project. Political risk insurance cover maybe taken to ward off this risk.

Although it is true that all investment projects involve some risk but High Speed rail projects are very vulnerable to risks which constraints it's financing.

Pricing of loan envisages that apart from covering cost of funds, profit margin, administrative costs and overheads, it should also cover the risk associated with the particular exposure for bank.

Another challenge of infrastructure financing pertains to measurement and monitoring of the performance of a project after financing. In financing and implementing infrastructure projects, social cost benefit analysis has assumed significance. The purpose of social cost benefit analysis is to supplement and strengthen the technique of financial analysis and not to do away with them.

Issues of human rights too assume significance as any dedicated high speed rail network project will lead to some displacement of people. Besides, complicated land acquisitions and compensation issue will definitely affect financing of the project. Amazon Road project of Brazil, Shell project in Nigeria are some examples where infrastructure projects got entangled in the human rights issues.

Due mainly to the above issues, financing of infrastructure projects has been traditionally, the responsibility of the government. However, today there is a gradual movement from pure public sector projects to various forms of Public Private Partnership (PPP).

Public Private Partnership brings together public and private sectors for the purpose of delivering a project. It is a medium to long term relationship and involves sharing of resources, risks and rewards between the public and private sector. The coming together of the public and private sector has a synergic impact. The public sector has the requisite means to support the project and insulate it from various uncertainties. The private sector partner has the expertise and funding ability. This collaboration can create successful ventures.

The key issue in PPP projects is the economic viability. To ensure this, it is necessary that a regulatory framework is in place to enable the private participant to operate in commercially viable way. It also requires that end user charges must be commensurate with the cost of the projects run by the private operators. Investment and backups of a suitable tenor should be available. High speed rail network project require long tenor debt and equity investments for the periods of long gestations.

There are some general criteria for financing high speed rail projects.

1. Systemic Reduction of risk : It has to be ensured that the invested amount will be paid in time without delay; which will mean that the project is financially viable with clear identifiable streams of revenue and the assets are professionally managed with adequate insurance cover.
2. Return on investment: It is reasonable for the private sector participants to expect a decent return on investments.

3. Certain relief by the Government: Government has to step in by way of part or full subsidy, guarantees, tax incentives, providing the land for the project at reduced cost, smoothening of procedures.
4. User charges issues: It is widely believed that high speed Rail projects should be economically self- sustainable. In many cases the end users are willing and able to pay for better infrastructure, but at the same time operating agencies cannot impose heavy user charges on beneficiaries.

Thus there has to be a careful balancing. A World Bank survey has indicated the following factors which determine the interest of international investors. These factors are as under:

1) Government and legislative process
    a) Administrative efficiency:- lead time to get approval and licenses
    b) Judicial independence: - degree of perceived independence from Government influence.
    c) Country ranking in Transparency International's corruption perception index.
    d) Regulations that clearly define and allow exit for investors in infrastructure.
    e) Reliance on a competitive bidding process to select project investor or purchaser.
2) The Economy:
    a) Investment grade credit rating for long term foreign exchange debt.
    b) Cost and available tenors to borrow in domestic market.
3) The sector's current status:
    a) Consumer payment discipline and enforcement
    b) Availability of credit enhancement and the guarantee from the government multilateral agencies.
    c) Availability to integrate with other segments of the chain, for example in high speed rail project its integration with

    other modes of transport will have a bearing.
  - d) Legal framework defining the right and obligation of private investors.
  - e) Independence of regulatory institution and processes from arbitrary government interference.

4) The political economy:
   - a) Tenure and stability of elected officials in political process
   - b) Negative perceptions and resistance to private investment among members of civil society.

The above factors must be taken care of to ensure the success of PPP mode in High speed rail projects.

There are enough indications to suggest that the Government is serious enough to remove the stumbling blocks and promote public private partnerships. Recently Government has permitted 100% FDI in high speed rail projects and has taken many enabling steps to ensure that financing for high speed rail project does not become a bottleneck.

During the visit of India's Prime Minister to Japan, the Japanese government pledged an investment of over 2.1 lakh crore over a period of five years. The investment will also be in the field of high speed rail projects. China also pledged support for India's high speed rail projects and agreements for cooperation were signed between Indian and Chinese railway during the visit of Chinese president to India in September 2014.

It may be instructive to know the funding pattern of high speed rail projects through PPP in different countries.

In china about 40-50% of financing of high speed rail project is provided by the national government through lending by state owned banks and financial institutions, another 40% by the bonds issued by the Ministry of Railway and the remaining 10-20% by provincial and local governments. The Ministry of Railway through its financing subsidiary, the China Rail Investment

Corporation, issued an estimated US$150 billion dollars in debt to finance the construction of high speed rail projects from 2006 to 2010. China Rail Investment Corporation has also raised some capital through equity offerings; in the year 2010, China Rail Investment Corp sold a 4.5 percent stake in the Beijing–Shanghai High-Speed Railway to the Bank of China for ¥6.6 billion and a 4.537 percent stake to the public for ¥6 billion.

Japan took the help of World Bank to initially finance the shinkansen project. For the construction of new shinkansen projects national government is bearing 66.7% cost partly through public work expenditure in national budget and partly through Revenue from the sales of Shinkansen lines to Japanese Railway companies. Local governments bear the remaining 33.3% of the cost.

The financing of the French high speed rail projects is characterized by three distinct phases: Public debt financing, debt combined with a range of subsidies and public–private partnership financing models. Initially the French high speed rail lines were financed mainly by French national railway on the basis of their estimated profitability, with investment proposals being evaluated according to both expected financial and social rates of return. French national railway decided to construct the more profitable lines first. The first line, from Paris to Lyon was financed entirely by French national railway on the basis of an expected minimum 12 percent financial rate of return. This line achieved spectacular success in terms of both traffic and revenue generation, and the achieved financial rates of return was estimated at between 15 percent and 30 percent per year in socio- economic terms and it was fully amortized by the end of 1993 just after 12 years of its operation. Encouraged by this success the French government made further contribution in many high speed projects like TGV-Atlantique.

French government set up a Railway infrastructure manager

RFF in 1998 and transferred all existing high speed rail project's debts to RFF while French national railway SNCF focused on the operation of these lines.

Recently France has maintained their stance to keep public subsidies to a minimum, all the while stating their firm commitment to keep extending the high speed rail network. This has resulted in a shift in financing model and involvement of private sector has been solicited and PPP model being tried out in projects like LGV SEA, LGV BPL, LGV CNM and Perpignan that includes Franco-Spanish cross border link.

Thus it is evident that Public financing has been the major source of finance for all high speed rail projects. PPP is being tried in few cases particularly in France. However, the need of the hour is to search for innovative financing methods.

High speed rail project can be successful in India. With the adoption of innovative ways of cost reduction, indigenization of technology, promotion of innovative financing methods the project can be a success. The project has to be implemented in a phased manner, it is necessary to understand the phases and stages of bullet train project. The Implementation guide will help us understand each and every step associated with high speed rail project.

6

Step by Step
Implementation Guide

The planning, design, construction and operation of bullet trains is a complex task and must be accomplished in a careful manner. The whole process of implementation of bullet trains is divided into various phases and stages. They are explained below.

The Emergence Phase

It is basically the phase when the idea of high speed rail project is generated. The objective of this phase is to finalize any appropriate authority which will undertake pre-feasibility studies based on socio economic and traffic projection analysis. The emerging phase is divided in two stages namely Emergence and Pre-feasibility stage.

At the emergence stage broad contours of the project are defined. While fate of the project is still uncertain at this stage, yet existing planning documents, data about current transport system and the travel requirements are used to decide about the project ownership, study the rail corridors where the project is to be implemented, etc. This stage is also used to create organizational structure which will carry out this project.

The pre-feasibility study includes verifying the viability of high speed network, transport demand modeling, identification of corridors and passenger and freight demand analysis. Patronage studies are undertaken first to determine its present demand, and secondly to forecast future traffic flows in the area both with and without the proposed investment according to the defined scenarios.

The Feasibility Phase

This phase is built on emergence phase and the following are the stages of this phase

Stage 2: Feasibility study

This stage has following objectives

- To identify the most effective high speed rail option for each corridor
- To establish medium level estimates costs
- To identify patronage compatible with a viable project
- To identify the most feasible technology
- To identify needs and benefits of implementing high speed rail system

The outcome of this stage is the development of land acquisition and funding plan. Feasibility design is also prepared.

Stage 3: Environmental Assessment

Environment is considered as a vital and inherent part of the project. It is also an instrument in design process. Besides, public consultation process is also carried out. The outcome of this stage is identification of mitigating measures, their definition and costs, preparation of environmental management plan and documents for statutory procedures.

Stage 4: Financial and Economic Analysis

Profitability of the project is estimated to identify the quantum of financial support requirement. Economics is worked out to find out if society will be better off with this project. The output is presented in the form of Financial and economic net present value and internal rates of return.

Stage 5: Multicriteria Analysis

This stage is fundamental for the high speed rail projects in that it will, in theory, culminate in the choice of a solution that will be studied in much greater detail during the next study.

It should enable the choice of a particular solution deemed to represent the best.

Solution in relation to the various parameters. Choice of well justified solution which can be presented for approval is the outcome of this analysis.

Stage 6: Preliminary Design

The purpose of the Preliminary Design process is to finalize the horizontal and vertical alignment of the railway line and prepare plan drawings. The plan drawings will also define the structures, tunnels, stations and rail facilities that are inside the scope of the project, besides the possible connections with other sections. This stage will also define and firm up the layout, preliminary design of structures, signaling, communication, power supply, depot, siding, workshop and system integration plans.

Stage 7: Empowerment

This stage takes place at the end of the feasibility studies, when the project is detailed enough, especially in environmental and safety terms, to convince all the stakeholders that process must go on and sources of funding must be identified. At this point of time the stage is set to get the green signal to go ahead with the project.

Design Phase

This phase has two main stages

Stage 8: Operation and Maintenance Planning

Operational planning is done to define speed, train capacity, headway, operational time table etc. program wide maintenance concept plan is prepared to define maintenance facilities for tracks, rolling stock, signaling system etc.

Stage 9: Detailed design

At this stage overall solution is fine tuned. Technical, architectural and landscaping choices are firmed up in greater detail. Land acquisition boundaries are fixed and work contracts are prepared and all tender related documents are prepared.

Construction Phase

Once the design phase is complete then the construction phase starts

Stage 10: Construction Planning

Meticulous planning is required to organize production work in the best possible way to ensure that the project deadlines are met. It also helps in finalizing the dates on which operation will start. Land acquisition procedure needs to be scheduled. Work testing and commissioning programs are also finalized.

Stage 11: Construction

At this stage infrastructure compliant with safety, quality and environmental management is created within the set deadlines.

Stage 12: Testing & Commissioning

Once such infrastructure is created it is necessary to thoroughly test it before commissioning. All the structure, system and sub systems are thoroughly checked for their compliance with safety norms. This stage aims to enable the new line to be placed in service.

Operation Phase

Now it is the time to operate and maintain high speed system with adequate availability, reliability, safety and maintainability. At this stage recruitment and training of manpower also becomes important.

Stage 14: Ex-post evaluation

At this stage assessment of the project is carried out to analyze and explain any disparities so that proper conclusion for future can be drawn.

This is the whole process of the implementation of bullet train project. This step by step guide gives an indication of the road ahead. Now let us examine the current status and future prospects of high speed travel.

7

Breaking of Sound Barrier and Space Travel on Earth

The current status and future of transportation

Detailed country wise status will make the understating of current status of High speed rail system more clear.

China:

China has the world's longest network of high speed rail with 9867 km in operation (on 1st Nov. 2013). This network of passenger dedicated lines is spread over 25 sections. Beijing to Shanghai is the longest section of 1318 km at a maximum speed of 300 km/h. Wuhan to Guangzhou is the second longest section of 1079 km and it also has a maximum speed of 300 km/h. Four sections viz Beijing-Tianjing, Shanghai-Hangzhou, Nanjing-Hangzhou and Hangzhou-Ningbo have a maximum speed of 350 km/h. Around 9081 km of dedicated high speed rail line is under construction in China. Two major sections under construction are Lanzhou-Urumqi section of 1776 km and Changsha–Kunming section of 1158 km. Furthermore additional 3777 km of high speed network has been planned.

China also has the distinction of having the world's only commercially operated Maglev train connecting shanghai city with its international airport at a peak speed of 431 km/h.The 30.5 km trip is covered in less than 7.5 minutes.

China initially acquired high speed technology from various countries like france, Germany, Japan etc. However it insisted on joint ventures, indigenous manufacturing and technology transfer clauses. China Rail High speed(CRH) is the name of Chinese high speed rail trains. CRH series trains built on foreign technology was first time introduced in service in 2007 but the first Indigenous high speed train of CRH series entered service on the Sanghai-Hangzhou High Speed Railway in year 2010.

Since the introduction of first CRH train in 2007, daily ridership has grown from 237,000 in 2007 & 1.33 million in 2012 making the Chinese high speed rail network the most heavily used in the world.

China has basically undergone an HSR building boom with generous funding from Chinese government's economic stimulus program. The network is rapidly expanding and is expected to reach 18,000 km by the end of 2015, including 6700 km of track capable of accommodating train speeds of 300 – 350 km/h.

China's high speed rail construction projects are highly capital intensive. Approximately half of the funds are provided by the national government through lending by Government banks and financial institutions. Around 40% funds are provided by Ministry of Railway and the remaining around 10% by local and state governments.

Japan

Japan has the distinction of being the first country in the world to start High speed trains on a dedicated new trunk line known as Shinkansen. At present Shinkansen system is operational over a network of 2664 km covering 15 sections. Tokyo-Tokaido section being the longest with 515 km. Another 779 km is under constructions and 179 km is at planning stage. The maximum speed of trains ranges from 240-320 km/h. Shinkansen system had the highest annual passenger ridership (a maximum of 353 million in 2007) of any high speed rail network until 2011 when China's HSR network surpassed it at 370 million passengers annually.

Shinkansen system is separate from conventional rail line. Tracks are isolated from public areas. The system uses tunnels and viaducts to go through and over obstacles. Standard gauge tracks are used with continuous welded rail and swingnose crossing points. Combination of ballasted and slab tracks are used. The system employs Automatic Train control system and 25000 V AC overhead power supply. The shinkansen system has very good record of punctuality as it is totaly separated from slower traffic and has very reliable technological set up. The safety record of shinkansen system is impeccable as there has not been a single serious accident in its 50 years of history and thus there has not been any casualty so far. Shinkansen technology is widely being used in countries like China, Taiwan, United kingdom, Brazil United states of America.

Spain

Spain with 2515 km of operational high speed rail network has the longest high speed rail system in Europe. Further 1380 km of HSR network is under construction and another 1702 km HSR network has been planned. **Alta Velocidad Espanola (AVE)** is a service of high speed rail in Spain operated by the Spanish national railway company, at a maximum speed of 300 km/h

AVE has a **service guarantee arrival system** in place in Madrid-seville section. Under the scheme full refund is offered if the arrival is five minutes beyond the advertised time, on other lines full refund is granted if the arrival is 15 minutes beyond the advertised time. Such cases are extremely rare due to maintenance of highest standard of punctuality. Spain and France are connected with a high speed rail network. The following routes are operational at present.

- Madrid - Barcelona - Marseille
- Barcelona - Paris
- Barcelona - Lyon
- Barcelona – Toulouse

This network covers 15 French cities. One more international line has been planned which will connect Madrid with Lisbon.

France

A total of 2036 km high speed rail system is operational in France in 9 different sections, the maximum commercial speed is 320 km/h. Total of 757 km of high speed lines are under construction and further 2407 km has been planned.

The TGV (Train a Grande Vitese, high speed train) is France's high speed rail service, operated by SNCF voyages, the long distance rail branch of SNCF. The TGV system has created many records in the field of high speed trains.

The current and proposed network is basically a group of four radiating lines from Paris. There are ten existing lines; four lines are under construction and twelve more lines have been planned. TGV Duplex is a unique feature of French high speed trains. This was specifically designed to increase capacity on highly saturated lines.

Bi-level carriages allow 45% more capacity than a single level TGV. These trains are quite popular and have helped in capacity enhancement in a big way.

The TGV technology is widely used even outside France. AVE in Spain, Thalys in Belgium, The Netherland and Germany, KTX in South Korea and Acela express in USA use TGV technology. SNCF and Alstom have developed new generation train named as **Automotrice à grande vitesse** (**AGV).** These trains have high-speed multiple unit with motors under each carriage.

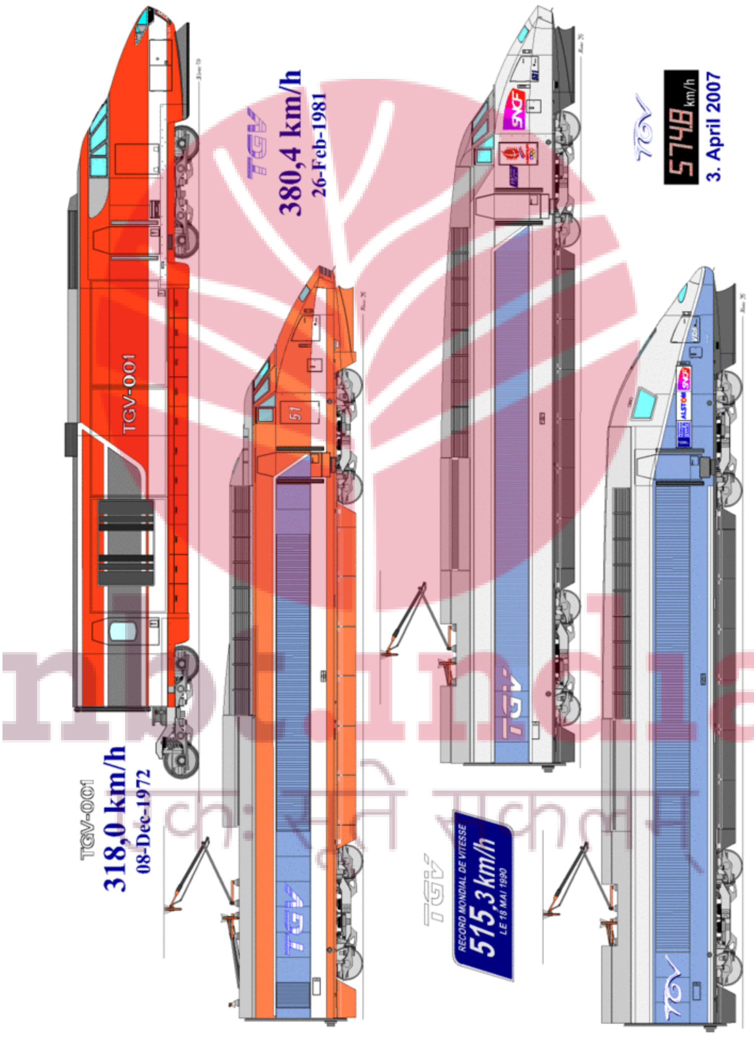

Fig. 7.1: Records set by French TGV. Source:en.wikipedia.org

Fig. 7.2: French Duplex train

The advantages of the AGV are: increased seating area per train length (compared to a single-deck TGV); lower maintenance costs due to Jacobs bogie articulation giving a low number of bogies per train; and higher energy efficiency, lower noise, and more space in the vestibules due to high power-to-weight ratio, high-efficiency permanent-magnet synchronous motors and other design improvements.

Germany

In Germany High Speed trains are operational over a network of 1334 kilometers, 428 km is under construction and 495 km more network has been planned. German high speed trains are popularly known as ICE (Intercity express). The maximum commercial speed is 300 km/h. The ICE network is very closely integrated with conventional rail network due to unique geographical features.ICE trains have also reached destinations in

Austria and Switzerland. Within Germany these are completely new construction projects:

- Cologne–Frankfurt high-speed rail line (300 km/h)
- Hanover–Würzburg high-speed railway (280 km/h)
- Mannheim–Stuttgart high-speed railway (280 km/h)

There are two partially new lines:

- Hanover–Berlin high-speed railway (250 km/h)
- Nuremberg–Munich high-speed railway (300 km/h)

Parts of these routes are new constructions that run along or close to the existing, or previous, route:

Transrapid is a German high-speed monorail train using magnetic levitation based on a 1934 patent. This is designed for a cruising speed of 500 km/h. The test facility for this technology was in Emsland which has since been closed as there are not many takers of the technology due mainly to cost, safety, health and environmental considerations. The only successful commercial application is being done by China.

Italy

In Italy high speed trains are operational over a network of 923 km. Further 395 km has been planned. High Speed rail in Italy consists of two lines connecting almost all the major cities of Italy. The first line connects Turin to Salerno via Milan, Bologna, Florence, Rome and Naples. The second runs from Turin to Venice via Milan. The maximum commercial speed is 300 km/h.

Italy is the pioneer in high speed rail in Europe and the original home of the pendolino trains.

Pendolino is an Italian family of tilting trains which is being used in various countries like Italy, Spain, Portugal, Slovenia, Finland, Russian Federation, the Czech Republic, the United Kingdom, Slovakia, Switzerland, China. Based on the design of the Italian ETR 401 and the British Advanced Passenger Train, it was further developed and manufactured by Fiat Ferroviaria which was taken over by Alstom in 2000. Pendolino uses Tiltronix anticipatory tilting technology so these trains can travel more rapidly through curves while ensuring top level of passenger comfort inside the train, even on very winding stretches.

Austria

High Speed trains are operational in the Vienna – St. Polten section at the maximum speed of 250 km/h. The section opened in 2012 and its length is 93 km. The high speed train of Austrian Railway is named **Rail Jet**. Rail Jet has three classes economy, first and business. Rail Jet is one of the most modern and luxurious trains in Europe. It operates mainly in Austria with international connections to Germany, Switzerland and Hungary.

Belgium

At present high speed rails are operational on four different routes covering a total 209 kilometers. Belgium's high speed rail network provides mostly international connections from Brussels to France, Germany and the Netherlands. The high speed network began with the opening of the HSL1 to France in 1997, and since then high speed lines have been extended towards Germany with HSL2 in 2002, from Liege to the Germany border in 2009, and HSL4 from Antwerp to the Dutch border in 2009.

Netherland

The Netherland is connected to the European high speed rail system with a high speed line of 120 km distance which is called HSL – Zuid (High Speed Line South). It uses existing track from Amsterdam Central to Schiphol Airport, and the dedicated high speed line begins here and continues up to Belgium border via Rotterdam central. It has the top speed of 300 km/h.

Switzerland

French TGV and German ICE lines extend into Switzerland, but given the dense rail traffic, short distances between Swiss cities and the mountainous terrain these trains do not attain speed higher than 200 km/h. Switzerland's own high speed Rail Network is in operation in Frutigen – VISP section of 35 km and has the maximum speed of 250 km/h. 72 km of high speed rail network is under construction in Erstfeld – Biasca and Giubiasco – Lugano section.

United Kingdom

At present United Kingdom has 113 km of operational high speed rail network. The first purpose-built high-speed rail line in Britain was the Channel Tunnel Rail Link, the first section of which opened in 2003. This line was re-branded "High Speed 1" in 2006. A second purpose-built high-speed line is now planned by the government and has been named "High Speed 2" which will connect London with Birmingham, and at a later phase cities in northern England (including Manchester, Sheffield and Leeds). Alongside this scheme, are plans by the Scottish Government to build a high-speed rail line between Edinburgh and Glasgow, this line is to be opened by 2024.

At present, a mixture of 300 km/h Eurostar international services and 225 km/h Southeastern domestic passenger services use High Speed 1. Attempts to increase speeds to 225 km/h on the East Coast Main Line and West Coast Main Line have failed, partly because trains that travel above 201 km/h are considered to need cab signaling for safety reasons. The term High Speed Train (or HST125) is currently also used as a brand name for the present British fleet of Class 43, 125 mph (201 km/h) Inter City diesel trains.

Poland

As of now there is no operational high speed rail system but it has around 700 – 800 km of railways suited for high speed train. The two planned lines are Warsaw to PoZnan via Wroclaw and Warsaw to Ktowice/Krakow.

Portugal

At present there is no organized high speed rail system in Portugal. A total of 1006 km has been planned for six different sections and with a speed ranging from 250 – 350 km/h. Comboios de Portugal (CP; English: ***Trains of Portugal***) is a state-owned company which operates freight and passenger trains in Portugal railways started the Alfa pendular service, connecting Portugal's mainland from the north border to the Algarve at a speed of up to 220 km/h. The service is operated using 10 Italian designed pendolino tilting trains. Apart from their high speed trains. Intercity 'Corail' coaches have been upgraded to 200 km per hour.

Sweden

As of now there is no operational high speed rail system. A total of 750 km of high speed rail network has been planned. In Sweden many trains run at 200 km/h. Train types which currently attain this speed include the X2 tilting trains for long distance and the Arlanda Airport express line X3. The X2 runs between many cities in Sweden including Stockholm, Gothenburg and Malmo. The Arlanda express train connects Stockholm – Arlanda Airport. There are plan for 750 km high speed Rail Network in Stockholm – Malmo/Gutenberg section.

Turkey

Turkey has two sections of high speed rail network covering a total of 444 kilometers. Another 603 km is under construction and 1758 km of high speed rail network has been planned. The maximum speed is 250 km/h.

In Asia apart from China and Japan Dedicated high speed rail network is operational in Korea and Taiwan.

South Korea:

At present high speed rail system in South Korea is operational over a network of 412 km. 186 km of high speed rail network is under construction and 49 km of HSR network has been planned. Korea Train Express (KTX) is South Korea's high speed rail system, operated by Korail. Top speed for trains is currently 305 km/h. the next generation KTX train – HEMU – 430X, achieved 421.4 km/h in 2013, making South Korea the world's fourth country after France, Japan and China to develop a high speed train running on conventional rail above 420 km/h.

HEMU-430X (standing for High-Speed Electric Multiple Unit 430 km/h experimental) is a South Korean high-speed train aimed for a maximum speed of 430 km/h. On 31st March 2013, it achieved 421.4 km/h in a test run, making South Korea the world's fourth country after France, Japan and China to develop a high-speed train running on conventional rail above 420 km/h. The main new feature of the train compared to older South Korean high-speed trains is distributed traction. The foreseen commercial version of the train, tentatively named KTX-III, would soon be in regular service with a top speed of 370 km/h (230 mph)

India

Right intent has been shown by the government and specific steps are being taken for the development of high speed rail system in India. One such step is the setting up of institutional framework.

High Speed Rail Corporation as a special purpose vehicle has been incorporated as a subsidiary of Rail Vikas Nigam Limited which is a Mini-Ratna Public Sector Enterprise of Government of India.

High Speed Rail Corporation has been set up with the following objectives:

1. To undertake feasibility studies and techno-economic investigations and prepare detailed projects and Bankability Reports of selected corridors for introduction of high speed train to India.
2. To plan design and freeze technical parameters for high speed Rail systems including fixed assets, rolling stock and operations.
3. To develop financing modals, explore Public Private Partnership options; coordinate with stake holders and funding agencies and to obtain various government approvals.
4. Project development, project execution, construction, upgradation, manufacture, operation and maintenance of High Speed Rail Systems and other rail based traffic as may be approved by Government of India or Rail Vikas Nigam Limited or any other authority created by the Government of such activities.

The Indian Railways' vision 2020 envisages the following on High Speed Corridors:

> "India is unique and alone among the major countries of the world in not having a single high speed rail corridor capable of running trains at speed of over 250 Kmph. Indian Railways would follow a two pronged approach in this respect. The first approach would be to raise the speed of segregated passenger corridors on trunk routes using conventional technology of 160 to 200 Km/h. The second approach would be to identify a number of intercity routes, depending on viability and build state of the art high speed corridors for speeds upto 350 Km/h on PPP mode in partnership with the State Governments. Partnership with the state Government would be crucial as real-

estate development would be a key element of viability of these high cost projects."

In the 2014-15 Rail Budget, it has been stated that we are embarking on an ambitious plan to have a Diamond Quadrilateral Network of High Speed Rail connecting major Metros and growth centers of the country. A provision of Rs. 100 Crores has been made in this budget for high speed project to RVNL/HSRC for taking further steps.

It also states that "while bullet trains would require completely new infrastructure high speed for existing trains will be achieved by upgrading the present network. Hence an effort will be made to increase the speed of trains to 160-200 Km/h in the select sectors so as to significantly reduce travel time between major cities." The identified sectors are:

- Delhi – Agra
- Delhi – Chandigarh
- Delhi – Kanpur
- Nagpur – Bilaspur
- Mysore – Bengaluru – Chennai
- Mumbai – Goa
- Mumbai – Ahmedabad
- Chennai – Hyderabad
- Nagpur – Secunderabad

Prime Minister of India, Shri Narendra Modi has listed a 17-Point Plan to take India forward. The first point of the agenda is to upgrade road and rail network in a manner that anyone can reach his/her destination anywhere in the country within 24 hours. To meet this requirement diamond quadrilateral of high speed network has been envisioned. The current status of various high speed rail projects can be aptly understood with the help of following picture.

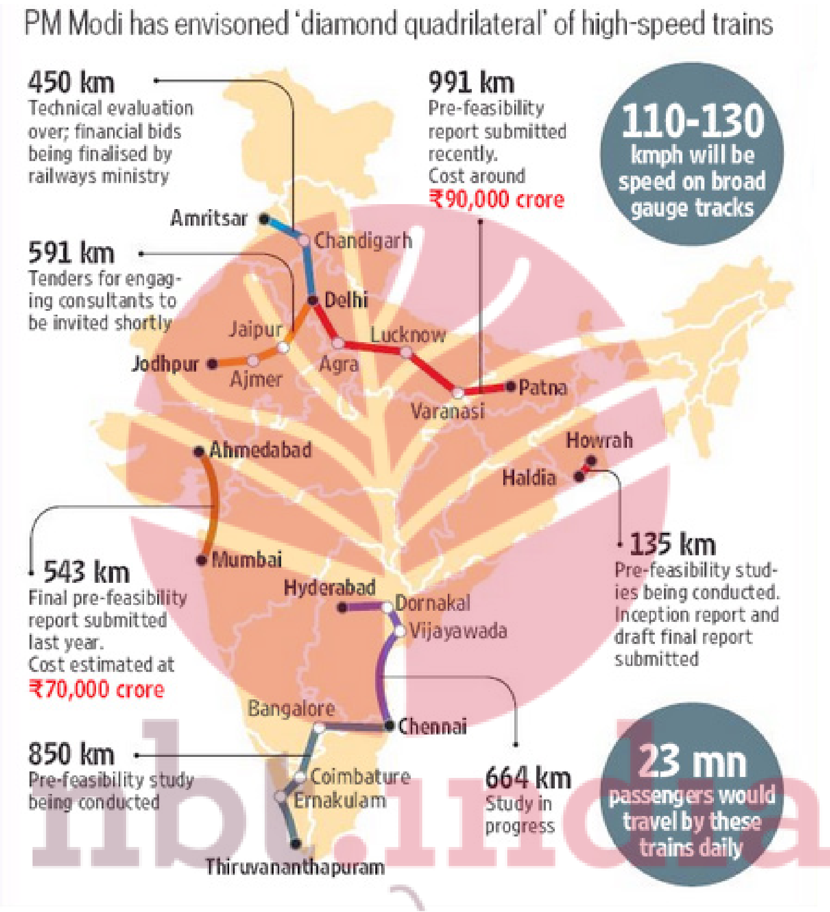

Fig. 7.3: Status of bullet train project in India (before 2014 rail budget)

Thus it is evident that India is moving towards having a high speed rail system. Now we have the situation when we have countries like Japan vying with each other for capturing the potential market of high speed trains in India. During the visit of Chinese president Xi Jinping to India in September 2014 an agreement has been signed between Indian and Chinese Railway according to which The China Railway Siyuan Survey and Design

Group and other Chinese enterprises will conduct the feasibility study for one high-speed corridor and prepare a project report with its financing. China will also assist Indian Railways with its semi-high speed plans. It will help strengthen tracks so that the maximum speed of passenger trains can be increased to 160 kmph from 130 kmph. To begin with, Chinese engineers will help commission the Chennai-Bangalore-Mysore corridor and help augment train for 160 kmph.

China is planning to outwit Japan by pledging to invest billions of dollars in India's railway, manufacturing and infrastructure projects. Chinese officials have taken a decision to scale up investments in India, especially after Japan made a splash with commitment to invest USD 35 billion during Prime Minister Narendra Modi's visit to Tokyo. China is positively considering investing in India's ambitious plan to build high-speed railways, including bullet trains.

Chinese officials say that China would be committing anywhere between USD 100 billion to USD 300 billion in the modernization of Indian railways by replacing existing tracks to increase the speed, station development, establishing industrial parks as well as invest in mega infrastructure projects.

The improvement of tracks could push the average train speeds from 160 km/hr to 180 km/hr.China is also asking India to hand over certain railway corridors for it to build,develop and maintain high speed railway lines. While Japan bagged the consultancy contract for Mumbai-Ahmedabad the first bullet train project of India, Chinese officials have evinced interest in Chennai and Bangalore and Bangalore-Mumbai corridors to build high-speed trains.

The first high-speed train is expected to run between Ahmedabad and Mumbai at an estimated cost of around Rs 60,000-70,000 crores. The high-speed rail (HSR) between Mumbai and Ahmedabad is likely to be operational by 2021 if everything goes according to the plan. HSR would cover the distance of 546 kilometer between Mumbai and Ahmedabad in just one hour and 52 minutes by running at a speed of 350 km per hour. If the speed was to be kept at 300 km/hour, then it would take 12 minutes more but could save 27 per cent energy.

The high-speed rail will cover 364 km in Gujarat, 176 km in Maharashtra and six km in Dadra & Nagar Haveli. A joint feasibility study for the Mumbai-Ahmedabad high-speed railway will be completed by July 2015. An interim report on the outcome of the study has already been submitted to both the governments.

The Mumbai-Ahmedabad bullet train may give stiff competition to flights operating in this sector. It has been proposed that some services on the high-speed corridor should be run at prices that will be competitive vis-a-vis airfares. It has been proposed that fare structure should be 1.5 times the existing 1st AC fare on existing train services in the sector. Non-stop trains between Ahmedabad and Mumbai can finish their journeys in just two hours. Flights on an average take 1 hour 15 minutes in comparison, It is estimated that most air line passengers would prefer to travel by bullet train if tickets are cheaper than airfare. The time difference between air and bullet train travel will be just 45 minutes. If you consider boarding and disembarking time for flights, the time difference, in fact, will be in favor of bullet trains.

Bullet fares will allow the high-speed system to generate around Rs 8 Crore in daily revenue. It is estimated that 40,000 passengers will be able to use the service by 2023. There will be 11 stations, including nine intermediate ones. "Not only non-stop trains, but also the other services will not halt at all stations. Each service will have no more than four or five halts to maintain high average speed. Such halts considered, the average running time will be 1 hour and 70 minutes. As these are based on preliminary studies so the various parameters mentioned above may change at a later stage.

McKinsey Global Institute report, states that 40 per cent of India's population would be globalised by year 2030. And thus there would be growing demand for inter-city transport-between metro city and tier-two and tier-three cities. He said that in the absence of high-speed rail, airlines and car traffic was growing at 15-20 per cent annually which is putting very heavy strain on environment and society.

Japan expressed readiness to provide financial, technical and operational support to introduce bullet trains in India in a joint statement issued during the visit of Indian Prime Minister to Japan in August 2014.

As Japan is a pioneer in running superfast trains, the agreement is expected to help India achieve its dream of a bullet train running at a maximum speed of 300 km per hour. Japan has agreed to provide financial, technical and operational support for the development of bullet train project in India. A joint statement to this effect has also been issued.

The joint statement paves the way for sorting out funding and technology issues related to the construction of the high-speed Ahmedabad-Mumbai corridor. The Indian government is insisting on a technology transfer to provide for indigenous manufacture of rolling stock (coaches, wagons, etc) and high-speed technology.

Whereas China's system has its advantage in lower construction costs and subsidies that its government grants to these countries, Japan's Shinkansen boasts a safety record that is free of any fatal operational accidents during a half-century of operation. The excellent safety record is because the Shinkansen system uses exclusive railway tracks without railroad crossings, which also enable trains to run on precise timetables.But the system poses a double-edged sword because of its higher construction costs and longer building schedule. It can also inconvenience users when they transfer from existing railway lines to a Shinkansen. Shinkansen technology, which also uses the automatic train control system, can be cost effective in the long run because it allows high-speed and high-frequency operations to meet increasing passenger demand in the future.

Japanese argue that if viewed from the mid- and long-term perspective, Shinkansen technology does not have cost disadvantages. However the competition for India's bullet train market is not restricted to China and Japan, many European nations like France and Germany are also making serious endeavors to grab this market.

The discussion so far has been about the status of current technology and the speeds in vicinity of 300-500 kilometer per hour. What sets the limit for the speed of land vehicles? For land vehicles breaking the sound barrier is still a great challenge. Sound travels at the speed of 340 meter per sec or 1224 kilometer per hour in air. Speed in excess of it is called supersonic speed.

The **sound barrier or sonic barrier is a** term for the sudden increase in drag and other effects experienced by any moving object when it approaches supersonic speed. When aircraft first began to be able to reach close to supersonic speed, these effects were seen as constituting a barrier making supersonic speed very difficult or impossible.

As the supersonic air movement creates disruptive shock waves and turbulence so propellers are known to suffer from dramatically decreased performance as they approach the speed of sound. All of these effects, although unrelated in most ways, led to the concept of a "barrier" that makes it difficult for an aircraft to exceed the speed of sound

The concept of sound barrier became popular during World War II, when a number of aircraft started to encounter the effects of compressibility, a number of several unrelated aerodynamic effects that "struck" their aircraft like an impediment to further acceleration. Design features like conical nose and sharp wing leading edges helped in the breaking of sound barrier. Bell X-1 was the first aircraft to break the sound barrier in level flight in 1947. By 1950s many aircraft had started to break the sound barrier.

The first manned Land vehicle to break the sound barrier was ThrustSSC (Supersonic car) when it achieved the speed of 1228 km/h on October 15, 1997. The car was driven by Royal Air Force fighter pilot Wing Commander Andy Green in Nevada, United States.

Fig. 7.5: Thrust SSC, the first manned land vehicle to break the sound barrier.

Breaking of sound barrier by manned land vehicle holds promise for development of technologies which may help in breaking of sound barrier by manned trains.

While talking of the future prospects of high speed travel one technology that must be deliberated is the Evacuated tube transport technology (ET3).

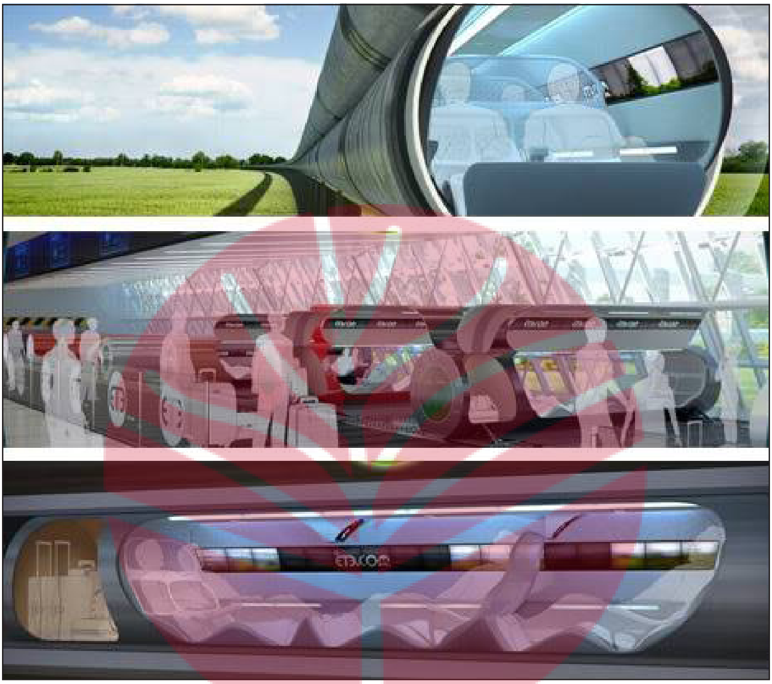

Fig. 7.6: Images of Evacuated Tube technology.

ET3 is literally "**space travel on earth**". Car sized passenger capsules travel in 1.5 meter diameter tubes on frictionless maglev. Air is drawn and permanently removed from the two way tubes that are built along a travel route. At stations the capsules are transferred using airlock so that air is not admitted. Once the linear electric motor accelerates the capsules, then it will coast through the vacuum without any additional power. As the capsule slows down the energy is regenerated. ET3 can provide 50 times more transportation per kWh than electric trains. This technology can be leveraged to carry water, sewer, oil gas, and garbage etc. all in special capsules. The initial speed of ET3 may be around 600 km per hour and may be developed to travel at a speed of 6500 km per hour and that will allow passenger and cargo to travel from Srinagar to Kaniyakumari in less than half an hour.

Notions need to be overthrown and new standards to be created to form our ideas for the future transportation.

8

Summing Up

High speed rail projects take time but good things come to those who are patient and stay the course. Research for high speed trains started way back in early 1900s and now there are plans for supersonic trains. Maglev trains in shanghai run at a regular commercial speed of 431 km/h. Trial run of French TGV has been successful at a speed of 574.8 km/h. The high speed rail system is operational in 15 countries and many other countries are likely to enter the high speed train club in near future.

Many European countries did many experiments in the pre Second World War era. But it was Japan which achieved the pioneer status by starting Shinkansen service in 1964. The success of Shinkansen renewed the interest of many countries and France National Railway showed commitment and started the first French high speed train TGV on its south-east line in 1981. China started late but today it has the distinction of being the country with longest network of high speed trains.

High speed rail is the most sustainable transport system. It offers numerous environmental, social and economic benefits. This mode of transportation has lowest energy consumption per passenger per kilometer and has the highest resource use efficiency. It has very positive impact on reduction of harmful emissions and thereby it is the most environment friendly mode of transport. This mode offers improved accessibility and mobility to all sections of the society. The region where high speed rail system develops gets very positive image and overall development of the region takes place. While making cost comparisons of different modes of transport the external costs are often excluded and that makes the comparison distorted. Once the external costs are properly accounted for the high speed rail system becomes very competitive on economic terms also.

Bullet trains are technological wonders of the world. The tracks, rolling stocks, operating and signaling system needs to be especially designed and built to meet the requirement.

Public financing has been the norm for funding the high speed rail projects. The government has financed capital costs and assumed the role of long term developer. The idea of Public private partnership has also been tried. The future will see use of innovative methods of financing.

The whole process of high speed rail project can be implemented in five phases viz. Emergence phase, Feasibility phase, Design phase, construction phase and the final phase of Operation and maintenance.

The idea of bullet trains in India is now taking shape in proper way. There is a firm commitment to build a golden quadrilateral of high speed trains. Mumbai- Ahmedabad section will be the first high speed corridor of India. Studies are being carried out and budget allotment has also been made for the purpose. Proper institutional framework has been set up and things are moving in right direction. India is ready to seize the moment and after all if Japanese can do it, Chinese can do it, French can do it, why can't India?

It is not that bullet train technology is the last thing in the field of transportation technology. Breaking of sound barrier by manned land vehicle has opened new frontiers and now we even talk of space travel on earth using ET3. The accustomed speed of travel is likely to change for better.

Glossary

Acces Plus: It is a special assistance services for persons with disability offered by French national railway. This service is available in nearly 360 stations throughout the French national network

AGV: The Automotrice à grande vitesse, is a standard gauge high-speed electric multiple unit train designed and built by Alstom. The maximum commercial speed is 360 km/h**.**

Articulated train: A railroad train whose cars are permanently or semi permanently jointed together for operation as a unit as distinguished from one whose cars may be readily uncoupled and operated in other trains

ATC: Automatic train control is a general class of train protection systems for railways that involves a speed control mechanism in response to external inputs. ATC systems tend to integrate various cab signalling technologies and the use more granular deceleration patterns in lieu of the rigid stops encountered with the older automatic train stop technology.

Atendo: It is Spanish railway's service for disabled people

AVE: Alta Velocidad Española: It is a service of high-speed rail in Spain operated by the Spanish national railway, at speeds of up to 310 km/h *Alta Velocidad Española* **translates to** "Spanish High Speed", but the initials are also a play on the word *ave*, meaning "bird". The AVE system is the longest HSR network in Europe and the second in the world, after China.

Bullet Trains: It is used interchangeably with high speed train. (See the definition of HSR)

Cab Signaling: Cab signaling is a railway safety system that communicates track status information to the cab of the train where the driver can see the information continuously. The simplest systems display the trackside signal, while more sophisticated systems also display allowable speed, location of nearby trains, and dynamic information about the track ahead. Cab signals can also be part of a more comprehensive train protection system that can automatically apply the brakes and bring the train to a stop if the operator does not respond appropriately to a dangerous condition

CBTC: Communications-Based Train Control system is a continuous, automatic train control system utilizing high-resolution train location determination, independent of track circuits; continuous, high-capacity, bidirectional train-to-wayside data communications; and trainborne and wayside processors**.**

CRH: China Railway High-speed is the high-speed rail service operated by China Railways. All high-speed trains in commercial use in China are named CRH. CRH1/2A/2B/2E/5 are expected to have a maximum speed of 250 km/h and CRH2C/3 have a maximum speed of 350 km/h. The new trainsets CRH380A have the maximum test speed of 416.6 km/h. The fastest trainsets CRH380BL have the maximum test speed of 487.3 km/h.

ERTMS: The European Railway Traffic Management System is a traffic management project developed by eight agencies namely Alstom Transport, Ansaldo STS, AZD Praha, Bombardier Transportation, CAF, Mermec, Siemens Mobility and Thales.

ERTMS has two basic components

ETCS, the European Train Control System, is an automatic train protection system (ATP) to replace the existing national ATP-systems;

GSM-R, a radio system for providing voice and data communication between the track and the train, based on standard GSM using frequencies specifically reserved for rail application with certain specific and advanced functions.

External cost: An external cost occurs when producing or consuming a good or service imposes a cost upon a third party. For example driving a car imposes a private cost on the driver (cost of petrol, tax and buying car). However, driving a car creates costs to other people in society. These can include:Greater congestion and slower journey times for other drivers,Cause of death for pedestrians, cyclists and other road users,Air and Noise Pollution and health related problems

HEMU-430X: It stands for **High-Speed Electric Multiple Unit 430 km/h experimental** and is a South Korean high-speed train aimed for a maximum speed of 430 km/h. On 31st March 2013, it achieved 421.4 km/h in a test run, making South Korea the world's fourth country after France, Japan and China to develop a high-speed train running on conventional rail above 420 km/h. The main new feature of the train compared to older South Korean high-speed trains is distributed traction

HSR: High Speed Rail can be defined as that high speed rail is a set of three elements with the following three criteria:-

1. Infrastructure

a) The infrastructure of the trans-European High Speed system shall be that on the trans- European transport network identified in Article 129C of the Treaty: those built specially for High Speed travel; those specially upgraded for High Speed travel. They may include connecting lines, in particular junctions of new lines upgraded for High Speed with town centre stations located on them, on which speeds must take account of local conditions.

b) High Speed lines shall comprise:
Specially built High Speed lines equipped for speeds generally equal to or greater than 250 km/h,
Specially upgraded High Speed lines equipped for speeds of the order of 200 km/h,

Specially upgraded High Speed lines which have special features as a result of topographical, relief or town-planning constraints, on which the speed must be adapted to each case.

2. Rolling stock

The High Speed advanced-technology trains shall be designed in such a way as to guarantee safe, uninterrupted travel: at a speed of at least 250 km/h on lines specially built for High Speed, while enabling speeds of over 300 km/h to be reached in appropriate circumstances; at a speed of the order of 200 km/h on existing lines which have been or are specially upgraded, at the highest possible speed on other lines.

3. Compatibility of infrastructure and rolling stock

High Speed train services presuppose excellent compatibility between the characteristics of the infrastructure and those of the rolling stock. Performance levels, safety, quality of service and cost depend upon that compatibility.

I) Infrastructure: Track built specially for high speed travel.

II) Maximum Speed Limit: Minimum speed of 250 km/h on lines specially built for high speed and 200 km/h on existing lines which have been specially upgraded.

III) Operating Conditions: Rolling stock must be designed alongside its infrastructure for complete compatibility, safety and quality of service.

The above definition is also used by International Union of Railway (UIC).

HSRC: High Speed Rail Corporation of India Limited (HSRC) has been formed on the directions of Ministry of Railways, Government of India, for development and implementation of high speed rail projects. This Special Purpose Vehicle has been incorporated as a subsidiary of Rail Vikas Nigam Limited which is a Mini-Ratna public sector enterprise of Government of India.

ICE: Inter City Express is a high-speed train that connects all major cities in Germany. With speeds up to 300km/h, this is one of the fastest ways to travel between cities such as Berlin, Hamburg and Cologne. The ICE has international connections to Denmark, the Netherlands, Belgium, France, Switzerland and Austria.

Jacobs bogie: Instead of being underneath a piece of rolling stock, Jacobs bogies are placed between two carbody sections. The weight of each car is spread on one half of the Jacobs bogie**.**

KTX: Korea Train express (KTX) is South Korea's high-speed rail system, operated by **Korail** the national railroad operator of South Korea**.**

Maglev: Maglev is the abridged form of magnetic levitation and is a method of transportation that uses magnetic levitation to carry vehicles with magnets rather than with wheels. With maglev, a vehicle is levitated a short distance away from a guide way using magnets to create both lift and propulsion.

Pendolino: Pendolino is an Italian family of tilting trains used not only in Italy but in many other countries.

PPP: Public Private Partnership is coming together of public and private sectors for the purpose of delivering a project. It is a medium to long term relationship and involves sharing of resources, risks and rewards between the public and private sector. The coming together of the public and private sector has a synergic impact. The public sector has the requisite means to support the project and insulate it from various uncertainties. The private sector partner has the expertise and funding ability. This collaboration can create successful ventures

RENFE: Renfe Operadora is the state-owned company which operates freight and passenger trains on the networks of the Spanish national railway.

RRF: Réseau ferré de France (French: ***French Rail Network***) owns and maintains the French national railway network. The trains are operated by SNCF, the national railway company.This was done to separate train operations from the railway infrastructure**.**

RVNL: Rail Vikas Nigam Limited is a Special Purpose Vehicle created to undertake project development, mobilization of financial resources and implement projects pertaining to strengthening of Golden Quadrilateral and Port Connectivity. RVNL has been registered as a company under Companies.

Shinkansen: The *Shinkansen* **literally means** *new trunk line* and is a network of high-speed railway lines in Japan. The maximum operating speed is 320 km/h. It got the distinction of being the first dedicated high speed rail line of the world with its start in 1964.

SNCF: (Société nationale des chemins de fer français; "National society of French railways" or "French National Railway Company") is France's national railway company and manages the rail traffic in France and the Principality of Monaco. SNCF operates the country's national rail services, including the TGV, France's high-speed rail network.

SPV: The **Special Purpose Vehicle** is usually a subsidiary company with an asset/liability structure and legal status that makes its obligations secure even if the parent company goes bankrupt. A corporation can use such a vehicle to finance a large project without putting the entire firm at risk.

Talgo: Tren Articulado Ligero Goicoechea Oriol, meaning Goicoechea-Oriol light articulated train, Alejandro Goicoechea and José Luis Oriol being the founders of the company. Spanish manufacturer of intercity, standard, and high speed passenger trains. Talgo trains are best known for their unconventional articulated railway passenger car that uses a type similar to the Jacobs bogie that Talgo patented in 1941. The wheels are mounted in pairs but not joined by an axle and the bogies are shared between coaches rather than underneath individual coaches. This allows a railway car to take a turn at higher speed with less swaying.

TGV: The TGV (French: *Train à Grande Vitesse*, high-speed train) is France's high-speed rail service. With peak speeds of 320 km/h, some 450 TGVs are now serving 230 destinations.

Tilting Trains: These are trains having a mechanism enabling increased speed on regular rail tracks. As a train rounds a curve at speed, objects inside the train experience inertia. This can cause packages to slide about or seated passengers to feel squashed by the outboard armrest due to its centripetal force, and standing passengers to lose their balance. Tilting trains are designed to counteract this effect. In a curve to the left, the train tilts to the left to compensate for the gravitational-force push to the right, and vice versa. The train may be constructed such that inertial forces cause the tilting (**passive tilt**), or it may have a computer-controlled power mechanism (**active tilt**).

TSI: Technical specifications for interoperability (TSIs) mean the specifications by which each subsystem or part of subsystem is covered in order to meet the essential requirements and to ensure the interoperability of the European Community's high speed and conventional rail systems**.**

Value capture: Value capture is the identification and capture of the increase in land value resulting from public investment in infrastructure. It is basically based on the principle that all those who benefit from a particular infrastructure or service should also pay for it.

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Bullet Trains are the modern technological wonder which has revolutionized the concept of transportation. This book covers the history and background of bullet trains. It examines the current status and future prospects of bullet trains in different parts of the world with special emphasis on India. The technology of bullet trains has been explained in a very lucid manner. Benefits and criticism have been dealt in an objective way. The issues of financing, implementation methodology have been dealt in separate chapters. This book is a must read for all young adults, transport professionals, researchers, railway employees, and travellers.