This document is dedicated to

Dr. A. P. J. Abdul Kalam
(Former President of India)
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MESSAGE

Transportation is the backbone for the economic development of any nation. It facilitates social interactions through movement of people and goods. India’s transport sector, is quite large and diverse.

In India, all the four modes of transport are not being utilized optimally. For instance, road sector is much ahead of other forms of transport for both passengers as well as freight movement. At present, the connectivity up to village level has improved. However, the major challenge is to give last mile connectivity to 1.2 billion people today and expected 1.53 billion populations by 2035. The per capita penetration of vehicles is increasing year by year and it is projected that cars & SUVs will grow 13 times whereas 2-wheelers will increase by 6.6 times by 2035 with respect to 2005 level. As a consequence, the energy demand in transport sector is also projected to grow at 5-8% per annum. In contrast, railways and airways sectors are facing capacity constraint; the potential of waterways, the most economical and environment friendly mode of transport, is not been harnessed to the extent it should have been. Recently several initiatives have been taken up to maximize its utilization so that the burden on road and railways is significantly reduced. Maintaining the growth of transport sector commensurate with the demand under the strict environment restriction regime is a big challenge, particularly in view of India’s ratification of National Determined Contribution under Climate Change context.

There is a need for the development of advanced technologies relevant to the needs of Indian situation, to provide safe, comfortable, reliable, economical and environment friendly transport system for all. Development of a robust transport system calls for holistic thinking and action, alongside synergistic cooperation amongst stakeholders towards harmonizing different interests, objectives and approaches.

I am confident that the Technology Vision 2035 – Technology Roadmap on Transportation technologies brought out by TIFAC would be of immense value to the stakeholders in taking informed decisions and determining their future course of action.

(Dr. Harsh Vardhan)
MESSAGE

Worldover, economic development and industrial growth are accompanied by rapid urbanisation. Mobility of human beings and all the other factors of production is very important to keep pace with all those developments and to sustain the pace already attained. Mobility is synonymous with transport infrastructure and various modes of conveyances that influence movement of people and goods from places of production to places of consumption. Therefore, the efficiency and efficacy of the transport system determine the very success of economic development. However, these systems depend on many factors like number of people, transport network, types of vehicles along with management thereof. We are at the cusp of a paradigm shift and the decisions taken at this point of time with regard to the transport systems and the choices we make today for realising them would lay a strong foundation for efficient future.

Inadequacy of infrastructure, imbalances amongst different modes of transport and suboptimal utilisation of the infrastructure already created due to lack of connectivity are the main challenges to be addressed, in this context. Further, there is a need to customise the available technologies to the Indian context and to develop indigenous solutions for environmentally efficient, eco-friendly and environmentally safer options.

I am sure ‘Make in India’ initiative will help in this regard. Similarly, through ‘Smart Cities’ project, the government intends to integrate various systems of efficient transport with other smart systems to effectively serve the requirements of the country.

I am happy that the Technology Roadmap and Transportation Technology brought out by TIFAC has captured all these aspects. This document will be useful to transport & infrastructure agencies, government, R&D institutes, academia and policy makers to prioritise technologies and their future course of action.

New Delhi
09.12.2016

(Y S Chowdary)
MESSAGE

India has embarked upon a fast growth path. Several initiatives like Make in India, Digital India, Clean Ganga Mission etc. are giving push to this growth agenda. The main challenge is to synchronise this growth with sustainability and equitability. Transport, infrastructure, energy, food, health, habitat etc. are the key components of this growth. I am happy that the Technology Vision 2035 document, prepared by TIFAC, has discussed all such issues.

Technology Vision 2035 document has recognized ‘Safe and Speedy Mobility’ as one of the 12 prerogatives which every Indian should be assured of in 2035. Ensuring last mile connectivity to every individual is the key target articulated in this prerogative amongst few others where the technology would play a key role in ensuring delivery of the targets.

Transport has been playing and will continue to play an important role for equitable distribution of resources in ensuring better life. However, rapid pace of urbanization has placed heavy demand on the urban transport systems, leading to traffic congestion, capacity constraints, environmental pollution etc. In this context, the transport technology roadmap prepared by TIFAC has addressed all such issues and has given possible solutions both in terms of technology and policy.

India needs to harness the potential of water transport as this will be cheaper in comparison to other modes and also environment friendly. Another important issue that needs to be given attention is preferential movement of perishable goods specifically agricultural commodities; this will not only make them available in the market at an appropriate time, but will also reduce spoilage.

I congratulate TIFAC for bringing out this roadmap at an appropriate time. The recommendations and also the future research agenda identified in this roadmap will be useful to all the relevant stakeholders.

(Ashutosh Sharma)
India is a large and diverse country with resources, production centers, markets and opportunities dispersed across her length and breadth; needing efficient transportation infrastructure for people to realise their full potential. Since independence, transport sector has been playing a crucial role of connecting cities, towns and villages. Technology Vision 2035 envisages everyone to be able to reach respective district headquarter within 3 hours, state capital within 5 hours and national capital within 8 hours. It further envisages access to public transport within a km from home with no two points to be more than one hour apart even in a metropolitan area.

Since independence, India’s transportation system has seen a paradigm change. Road infrastructure, both highways as well as rural road networks, as well as air transport infrastructure, have seen impressive growth.

There is however an imbalance in the load on different modes of transport. For example, there is disproportionate growth in personal automobile transport in preference to more efficient integrated mass transportation systems in our cities leading to traffic congestion, delays in travel time, greater fuel consumption and higher level of pollution. Roads being the dominant mode of transport carry about 60% of freight and 87% of passenger traffic. This leads to greater energy consumption, increase in pollution, greater wear and tear and higher level of transport risks.

Indian Railways, one of the largest rail network in the world, carry around 1.50 crore passengers and 1.65 lakh tones of freight daily on its network of 64,000 route kilometers. Railway tracks as well as rolling stocks are however overburdened and need improved inspection and maintenance along with significant expansion. Growth of rail transportation infrastructure, even though more energy efficient and has lower transportation risks, has not kept pace the needs.

Limitations on ground as well as rising expectation on faster mobility, along with needs of growing economy, have led to rise in the demand for air transport. While India has taken good steps in modernizing most of the airports and impressive growth has been registered, there are challenges of congestion in airspace as well as at airports.

Though shipping is the most environment-friendly and economic mode of transport, its full potential has not yet been exploited. Water transportation has remained neglected by and large and is receiving attention in recent times.

Transportation today is largely dependent on hydrocarbon fuel most of which we import. India’s energy import bill is expected to see a steep rise in years to come. This along with concerns related to climate change arising out of use of fossil energy necessitates transitions to meeting energy needs of transportation systems without depending on fossil hydrocarbons or even better with use of fuels based on non-fossil primary energy. There is thus importance to electric mobility as also to futuristic synthetic fluid fuels produced using non-fossil primary energy.

On vehicle technological front, several new innovations are around or are on the anvil. They have the potential to significantly reduce transport time, be more economic and environment friendly, be adapted to local needs and be more
passenger friendly. To cope up with the challenges, integration of different modes is extremely urgent. Therefore, Intelligent Transport System (ITS) could be an appropriate way forward. This would enable vehicle to vehicle, vehicle to infrastructure and vehicle to passenger communication which will make transport system more efficient and convenient. This along with various innovative transport models will lead to realization of the vision of the transport sector “Sustainable, clean, safe, inclusive, smart and integrated mobility system.”

Keeping in mind of India’s diverse demographical needs and geographical spread as well as the demands for low cost, energy efficient, smart as well as rugged transportation system, solutions straightaway picked up from elsewhere may not directly fit in with our needs. There is a need to recalibrate such technological solutions keeping in mind our specific situation.

Transportation was identified as one of the key technology sectors in the Technology Vision 2035 exercise under way at TIFAC. Safe and speedy mobility is one of the twelve prerogatives identified for Indians in 2035. The sectoral group on transport has deliberated on the future trends in transportation systems and related technologies. Relevant ideas have been brought out in this roadmap document. Expectedly, they would be useful to stakeholders - Academia, R&D Institutions, Industry and Government in prioritizing their research and development as well in preparing their future action plan taking transportation systems in the country to next level consistent with the needs of Indians in 2035.

My heartiest congratulations to the team lead by Shri Shrikanth Marathe, Former Director ARAI for putting in their best effort in bringing out this document.

Dr. Anil Kakodkar
Chairman,
TIFAC.
Progress of a nation without transportation is unthinkable. Mobility is a basic human right. Unless there is a good, safe, comfortable, efficient transport system which causes the least damage to the environment, country will not be able to move ahead in the global context. This report covers all modes of transport, viz., Road, Rail, Air and Water. Each sector, takes a stock of the developments that have taken place in India since independence, brings out the technology gaps between the developed nation and India and highlights the areas where we need to concentrate in future to bridge the gap at a much faster pace than that achieved in the past. The report also delves into “Blue Sky Research” in each mode of transport. In today’s technological arena the word “impossible” has no room: whatever thoughts just as pipe dream a few decades ago, has turned into reality now. Latest example is of micro machines where a working automobile of a dimension lesser than the thickness of hair has been achieved by scientists who have been honoured by a Nobel Prize this year.

Integrated Transport Policy is need of the day. Need for intermodal cooperation alone will be able to provide efficient transport to all. In the past, different modes have been competing with each other leading to sub optimal solutions. Technology Vision 2035 has provided an opportunity to give a holistic view of transport for future covering all modes of transport. In some of the sectors like automobiles and railways to some extent, our industry has progressed quite well in the design activities while in waterways and airways, leaving aside the defence segment, we are only involved in operational management. We, as a country, need to enter into research, design and development and manufacturing activities in all the sectors.

The report is not an end in itself. We need to continuously look at the future and keep on updating it periodically based on the new knowledge and technology generated.

AUTOMOBILES

“Carriages without horses will go
And accidents fill the world with woe”

(Mother Shipton, circa 1530)

Unfortunately, presently we are facing this situation in India which was predicted almost 500 years ago. Road transport which had a very small share in 50s, has now outgrown all other modes of transport and has resulted in many problems of safety, air quality, and sustainability. Many challenges are ahead of us to tackle all these issues, escalated in the last three decades.

Road transport has been growing since 50s in a big way and especially had a phenomenal growth over the last 3 decades when the first modern cars and motorcycles entered the country. This has resulted into the problems of air quality, safety and sustainability. India has been continuously bringing in regulatory emission norms since the year 2000 and we are now looking forward to BS IV vehicles throughout the country in 2017 and jumping to BS VI vehicles in 2020, skipping
one stage of norms. Safety norms are also being introduced progressively in 2 wheelers as well as cars, commercial vehicles, and buses with a hope to bring down the ever increasing fatalities on road and then reversing the trend to achieve a “Zero Vision” of safety.

India, however, has a large population of old vehicles which need to be taken care of for improving the environment. Inspection and Maintenance regime needs to be brought into the system which will ensure health of all the vehicles running on road. This is one of the urgent needs to realise our dream of better air quality and safety. The report discusses this issue in detail.

Today, the whole world is heavily dependent on information and communication technology. In road transportation “Intelligent Transport System” plays a vital role in achieving the goal for better environment and improved safety. We need to leverage India’s strength in these areas by introducing smart vehicles and smart road infrastructure which will tremendously help in providing efficient, safe and sustainable road transport and also save enormous human hours which are lost for ever. We have to get into this area without any delay as every day the problem is going out of our hand for want of such enabling systems in India. Such systems are deployed all throughout the developed world.

Electric Mobility has assumed a far greater importance all across the world and India has also published its intent through National Electric Mobility Mission Plan. Several incentives have been offered for manufacturing and using electric vehicles. Electric and hybrid vehicles will contribute substantially in cleaning up air in the cities. Lots of research are required in the battery technology, battery management system, power electronics, controller, etc. This is totally a new area for India and needs to give a big thrust in the next 4–5 years to realise its benefits.

TV 2035 Report looks into all these areas and highlights the short term, medium term and long term plans which need to be taken up by us for future sustainable growth. We have been addressing these issues in a fragmented manner in the past and to realise the full benefits of such initiatives, it is essential to look at the sector in a holistic way to decide the action plan.

We cannot avoid looking at the Blue Sky Research areas including autonomous vehicles which pose many challenges to our engineers in view of our unique situation involving motorcycles, cars, trucks, buses, pedestrians, cyclists, etc. Importing just the solutions from abroad will not be effective. We need to have unique solutions catering to our unique situation.

**RAILWAYS**

Railways in India was once the major mode of transportation catering to almost 55% of the mobility needs. The share has gone down substantially as the growth of road transport overtook the growth of railways. The report covers the progress of railway transport over the last 70 years and highlights the need to concentrate more on this mode of transport. Railways have by far very low emissions and energy requirement compared to automobiles. In developed countries railways cater to almost 60% of freight transportation which eases out the stress on highways. India needs to look at dedicated passenger and freight lines which can bring efficiency and speed in this mode of transport. While the developed countries like Australia have goods trains with about 680 wagons and 7.2 km long train, we still are struggling with 58 wagons which put in severe constraints on the freight movement. Even though, there is tremendous increase on the passenger and freight needs since 1950, the railway infrastructure is almost stagnant which has resulted in putting severe strain on railways. The report stresses the need to concentrate on railways to bring in new technology to alleviate the pains. Design simulation will be needed for bringing in speed in the design process thus reducing development time. We need to get technology from abroad in the areas of high speed trains reaching up to 350–400 km/h, tilting wagons suitable for such high speed trains, lighter wagons to improve Payload/Tare weight ratios, improvements in aerodynamics, NVH (Noise, Voice and Harshness) issues, comfort factors, safety and security issues, electronically controlled braking systems, intelligent adhesion control systems, signalling and traffic management,
refrigerated wagons and a host of such technologies, essential for progress of this segment. Predictive maintenance techniques will be vital to maintain a network of such high speed trains without any loss of time due to breakdowns. Complete indigenous development in all these areas will not be possible and wherever possible, we need to bring in technology from abroad to cut down the development time. However, our internal efforts also should continue to delve in these high end technology areas as any country cannot depend fully on importing technologies for ever. In the concluding pages the report lists out all the areas of development categorised in short term, medium term and long term. There is also some discussion on Blue Sky Research areas including moving platforms, hotline maintenance aspects, etc. Since a lot of time is lost due to stagnancy for the last 40~50 years, a big leap is needed to catch up and be technologically competitive with the rest of the world.

**AIRWAYS**

Indian aerospace industry has registered substantial growth over the last 30 years. Annual passenger transport of 20 million annually has risen to 225 million in 2015. Natural fall outs are traffic congestion, emissions, and noise. While India has a fleet of the latest commercial aircrafts, there is a gap between the airborne and ground technologies and needs to be enhanced. Aerospace R&D, manufacturing has been an exclusive domain of the PSUs like HAL, NAL and defence laboratories. The private participation has, however, increased from 26% in 2001 to 49% in 2015 which is a good sign for the manufacturing industry in the country. A detailed policy plan for this sector needs to be evolved since the investments are very high, needing commercial viability as a major consideration for investments. The report brings out short term, medium term and long term efforts needed for the country.

**WATERWAYS**

Waterways has been one of the neglected areas for a long time in the country. In spite of the fact that waterways is the most economical and environment friendly mode of transport, there is no major development in the country for the last five decades. Importance of shipping is best expressed by Mr. Metropolous, Secretary, IMO as “But for shipping, half the world would have starved to death and the other half would have perished because of freezing cold.” India has 7500 km of coastline and 14000 km of navigable rivers and canals which need to be leveraged. The report covers various technological, commercial and operational issues related to the shipping industry. India’s shipping tonnage of just 1% of the world highlights the importance that needs to be given to this sector. We need to concentrate in developing a merchant fleet with balanced representation in all segments, viz., crude oil, coal, container trade, etc. Cabotage regulation which promotes domestic cargo by indigenous ships, flying under national flag needs to be promoted. Indian shipbuilding needs to be promoted. Hull and propeller design, hull coatings, air lubrication, lightweight materials, waste heat recovery, use of bio fuels, LNG, solar energy, wind energy need to be looked at for future technological progress in shipping. The set back this sector has experienced in the past needs to be corrected to enjoy the fruits of better environment and sustainability by increasing the share of this sector in the transport needs of the country.

This report has brought out the major issues that need to be considered for future and highlights the technological areas which need concentrated effort from all the concerned stakeholders.

Shri. Shrikant Marathe  
Chairman, Advisory Committee  
Transportation  
Technology Vision 2035  
TIFAC
After release of Technology Vision 2035 by Hon’ble Prime Minister in January 2016, TIFAC has been releasing Technology Roadmaps in 12 sectors one by one which are designed to give details of technology at various stages required to achieve the vision outlined as “Technology in the service of India: Ensuring the security, enhancing the prosperity and strengthening the identity of the every Indian”.

In the vision document, specific targets are identified under each of the 12 different prerogatives. ‘Safe and Speedy Mobility’ is one such prerogative. Providing connectivity anywhere, anytime to anyone is the backbone for this prerogative. Some of the key specific targets set under this prerogative are:

1. Technology should enable us to access public transportation within one km from our home
2. No place will be more than three hours away from a district headquarters, five hours from the state capital and eight hours from national capital
3. Every village connected with an all weather road.
4. Zero pedestrian fatalities due to traffic accidents.

Since time immemorial, mobility is the key component for survival of human beings as well as other living beings. Technological advancement is one of the key drivers for improvement in mobility. In fact, now we are starting to see even mobility to outer space as a result of technological advancement. Transportation sector is going to be an important sector to fulfill these and other targets defined in the vision document.

The technology roadmap exercise on transportation was started with the first brainstorming meeting held in Nov, 2011 in TIFAC, Delhi. Experts from leading automotive industries, R&D institutes, academia and government departments participated in that brainstorming meeting. I express my thanks to all the stakeholders who were present in the brainstorming meeting, which set the stage for this exercise.

An advisory committee was formed to steer and guide the sector with Shri. Shrikant Marathe, (Ex-Director ARAI), Pune as Chairman. Other members of the advisory committee were: Shri. Manoj Singh (Advisor, NITI Aayog), Dr. Aravind Bharadwaj, (VP Mahindra Research Valley), Shri. R.K. Pandey (Advisor MoRTH), Shri. Amitabh Ojha (RDSO), Shri Amitab Banerjee, (Ex-DG shipping), Ms. R. Savithri, (Director, Ministry of Statistics and Programme Implementation) with Dr. Gautam Goswami (Head TV 2035 exercise) and Ms. Mukti Prasad (Scientist C, TIFAC) as member secretary.

As a result of various rounds of discussion within the advisory group, four sub sectors of transport - roadways, railway, airways, and waterways were identified. The roadmap details each of these sub-sectors broadly on the issues such as; energy, environment, safety, control and management aspects, besides covering the current status both in India and globally, future technology trends, gaps, challenges and policy imperatives. I would like to express my gratitude and thanks to all the advisory committee members for their valuable inputs and time in the preparation of this roadmap document.
Subsequently, authors for each of the sub-sectors were also identified by the advisory committee. Roadways section was written by four authors namely; Prof. Avinash Kumar Agrawal (IIT Kanpur), Dr. S.S. Thipse (ARAI Pune), Dr. Akhilendra Pratap Singh (IIT Kanpur) and Smt. Mukti Prasad (TIFAC) whereas Railways, Airways and Waterways sections were authored by Dr. Sadasivan (Advanced Rail Control, Pvt. Ltd., Bengaluru), Shri. Atul Maindola, (DGCA, Delhi), Shri. Rajeeva Prakash (Indian Marine University, Chennai). I express my gratefulness for their immense contribution in authoring each of the sub sectors of the roadmap report in detail.

I appreciate the effort by the TIFAC scientists namely Shri. Arghya Sardar, Shri. Yashwant Dev Panwar, Smt. Nirmala Kaushik and Shri. Suresh Babu for their inputs in the document.

A dedicated TV 2035 team headed by Dr. Gautam Goswami along with Dr. Neeraj Saxena, Smt. A. Jancy, Dr. T. Chakradhar, Smt. Mukti Prasad, Shri. Manish Kumar and Ms. Swati Sharma had provided their inputs throughout the process and contributed profusely in editing and designing process.

I am confident that pathways defined in this document along with future technologies and the policy imperatives will be of use to all the relevant Ministries, R&D institutes, academia and industries in planning their future research as well as in achieving the set of targets mentioned in the technology Vision 2035 document.

Prof. Prabhat Ranjan
Executive Director
TIFAC
By the year 2035, the Indians will outnumber the Chinese. With an expected population of more than 1.50 billion, the demands on India’s transport sector will increase considerably. India’s trajectory of growth in the coming years depends significantly on how far technological innovations can strengthen the transport infrastructure and services, notwithstanding the fact that in the past India’s transport sector has trailed India’s economic growth. Functioning as the arteries of the nation, the various modes of transport – road, railways, water, and air – are tasked with providing good physical connectivity as well as quick and smooth movement of goods. For all practical purposes, a sustainable transport system must offer mobility and approachability to the people in the country as well as a safe, minimally wasteful and quick passage of goods from the supplier to the consumer in a risk-free and eco-friendly way.

Comparatively, each of the four modes of transport has their pluses and minuses. Roadways are the most extensively laid and most immediately available as also the most the most energy wasting and carbon emitting. Railways are the most economical and preferred in long distances but are, technologically, the most in need of upgradation. Airways, although expensive, provide the fastest and technologically the most superior mode of transport. Waterways carry the bulk of the international trade with minimal carbon footprint, however are relatively undeveloped for internal movement of goods and travel in India.

ROADWAYS

The bulk of domestic freight and passenger traffic is carried by Indians roads. Spanning over 5.23 million kilometers, Indian roadways have been able to traverse into hitherto unreachable areas carrying 65 per cent of domestic freight and 87 per cent of passengers. Road mobility in India has risen from around 3400 billion passenger-km in 2004-05 to over 8000 billion passenger-km in 2012-13 and is touching to a figure of 11000 currently. The number of registered vehicles in India is constantly rising, ramping up the pressure on the fragile road infrastructure. At the end of 2013, the number of registered vehicles in India was 182 million. This figure is expected to grow three-fold by 2035. Consequently, road congestion, air and noise pollution, travel safety, lack of skilled manpower, poor or lack of infrastructure are some of the challenges which confront the roadways sector.

The intervention of technology in the road transportation sector can help in easing the pressures on each of the problem areas listed above. In order to ease out congestion issues, Intelligent Transport Systems need to be invested in. Technologies for traffic management, freight information systems, electronic toll collections, vehicle to infrastructure communication, intelligent speed management, incident detection and GPS and navigation systems are increasingly available. Intermodal transportation mechanisms are in dire need to be smoothened. With emission norms being gradually standardized and implemented in vehicles, technology solutions for emission reduction span from engine downsizing to alternative combustion to alternative fuels. While in the short term, shifting from petroleum products to natural gas seems desirable, in the long run biofuels (preferably 3rd generation), synthetic fuels, fuel cell vehicles, use of solar powered vehicle would serve as sustainable alternatives. Shifting to electric and hybrid electric vehicles would also aid in fuel efficiency and emissions reduction. Besides all these, fuel efficiency would also benefit from innovation in vehicle design as well as through the use of advanced friction reduction light weight materials.

With only one per cent of the number of global vehicles, India contributes to ten per cent of deaths in road accidents worldwide annually. The report also calls for a safety roadmap with focus of technologies in both vehicle and road designs that augment travel safety. Meanwhile, investments in better road infrastructure would automatically help in reducing congestion and pollution and increasing efficiency. However, since it will not be possible to homogenize the quality of road across...
the breadth of the country, road maintenance will have to be prioritized according to considerations of the relative costs and benefits of primary, secondary and tertiary road networks. Further, a strong vehicle inspection and certification is required to improve the condition of the in-use vehicle fleet. Finally, this report lays emphasis on five I’s for transport – Integrated, Intermodal, Inclusive, Innovative and Intelligent – for a sustainable, clean, safe, inclusive, smart and integrated mobility system.

RAILWAYS

Aptly considered the lifeline of India, railways remains the preferred mode of transport of the common man in India. Compared with road transport, it is inexpensive, fuel efficient and environment friendly. With a total route of almost 65,000 kms, India boasts of the second largest rail network in the world. However, railway is also technologically one of the least developed modes of transport in India. In the 66 years of independence, only 21.5 per cent of new route kms have been added and the maximum commercial speed has only increased from 80-100 km/h to 140 km/h (while average speed is much lower at 110 km/h). This starkly contrasts with the global picture where commercial speeds in excess of 300 km/h have been consistently maintained by trains in Germany, China, France, South Korea, Taiwan, Spain, Japan, Italy, Belgium and the UK. The technological gap between India and the developed world is also considerable in heavy and long freight operations, axle load capacity, Payload to Tare Weight ratio of wagons, braking systems, intelligent adhesive control systems, signaling and traffic management, and passenger comfort.

The status of indigenous technologies in this sector is still relatively undeveloped. Hence, reliance on foreign technologies is imminent. Unlike some of the more sensitive areas like defence and space, railways technologies are available for sourcing from outside and technological partnerships with the best in the world are possible. However, high costs may be a prohibitive factor. A rational strategy would be to import technology initially followed by indigenous development for long term sustenance.

One of the major problem areas in the sector is the non-availability of separate tracks for passengers and freight. Having dedicated tracks for each of these functions would increase the speed and efficiency of the railways immensely. Besides, short term, medium term and long term goals with regard to the issue areas mentioned above have been identified in the report to help strategize the technological leap that India railways so badly needs.

Finally, fuel efficiency and emission control ought to go up in priority. Electric locomotives and other equipments must be designed to minimize energy waste and maximize regenerative capacity. Smart railway energy grids and piezo-electric power derived from floors of station area made of piezo-electric crystals need to be developed to better utilize energy. Moreover, alternative fuels such as hydrogen fuel cells and other renewable sources of energy must become the focus of research and development activities. The report also focuses on the futuristic train technologies which include high speed bullet trains, magnetic levitation (maglev) trains, evacuated tube transport (Hyper loop).

WATERWAYS

Water transport is the most economical and environmental friendly of all the modes of transport. The value of fuel consumed by water transport is 30 per cent of the fuel consumed by road and the emissions are one sixth of that by road and 50 per cent of that by railways. Consequently, over 90 per cent of the volume and 70 per cent of the value of global trade is transported through waterways. For India, with over 7500 km of coastline alongwith 13 major and 200 minor & intermediate ports and 14,500 km of navigable rivers and canals, water transport is a very conducive mode for both passenger and freight transport. In 2012, India’s maritime trade was US$794 billion. However in terms of relative output India’s share of maritime trade is declining. In 1950’s, maritime trade accounted for over 90 per cent of total India’s international trade. It reduced to 30 per cent in the 1990s and only 8 per cent currently. India’s international trade has declined from over 90 percent in the 1950s, to 30 percent in the early 90s, to less than 9 percent presently. The share of inland shipping is a meager 1 percent, while coastal shipping constitutes 7 percent of the total domestic cargo movement in India. This pales in comparison to 57 per cent and 34 per cent by roads and railways respectively. But the increasing delays in transporting goods due to high road and rail congestion is going to force the
adoption of waterways as a preferred mode of transport and will provide impetus to the growth of coastal and inland shipping network in India in the future.

There are number of factors, contributed to the relative slow growth of the maritime dimension of India’s trade. First, India’s shipping industry has not caught up with India’s burgeoning trade. Slow growth of tonnage in India has led to gradual decline in share of Indian companies. Thus, India’s trade remains heavily dependent on foreign shipping companies for transportation needs. Second, India has not had an integrated transport policy to promote inter-modal coordination leading to sub-optimal use of resources and their allocation to different sectors of transport. Third, although India’s overall share in global shipbuilding industry was miniscule, India had made good progress in shipbuilding in the 10th plan (2002-2007) by increasing its global share in commercial shipbuilding from 0.12 per cent to 1.3 per cent. Fourth, India lacks adequate port infrastructure to accommodate large size vessels. Moreover, India does not have any transshipment hub ports in the country and thus is dependent on feeder services from international hub ports in other countries for its cargo and goods. Consequently, not only does India miss on potential revenue from transshipment hubs, but it also ends up paying more charges for additional handling.

With the increasing trend of the international trade activities and also the dependence of India for the import of oil and gas, emission from the maritime sector are bound to increase. Therefore, there is a need to identify the new and advanced technologies to reduce the emissions. The future of maritime transport lies in the development of “greener ships” with zero emission by fully harnessing the technological advancements. Safety and security aspects of maritime transportation will also need to be addressed simultaneously. New benchmarks like Energy Efficiency Design Index (EEDI) and Ship Energy Efficiency Management Plan (SEEMP) have been introduced to make ships about 30 per cent more efficient. On engineering aspects, new technologies for hull and propellers, hull coating, hull air lubrication system, use of hybrid lightweight material for ship construction and improvement of propeller efficiency are being developed. Moreover, alternate fuels such as bio-fuels, LNG, solar energy, wind energy and fuel cells are exciting areas of research on which India must invest in the medium to long term. Having successfully launched a nuclear submarine, Arihant, India could make use of nuclear fuel, especially in the short to medium term. Using shore electricity when the ship is in port offers huge potential for emission reduction. Navigation technology is another area where India has shown potential, especially with the Indian Regional Navigational Research Satellite System (IRNSS). Other key futuristic technology includes hydrogen as an alternative fuel, use of nanotechnology, 3-D navigation charts and shipping across the Arctic.

**AIRWAYS**

Air Transport is one of the most technology intensive industry and have transformed the human aspirations of mobility and made this world truly flat by destroying distances. Air transport has consistently exhibited high level of growth in India over the last decade. Between 2006-07 and 2015-2016, passenger traffic grew by a CAGR of ten per cent. Significantly, the figures for passenger traffic are expected to undergo a threefold leap from 150 million passengers in 2011-12 to about 450 million in 2020, catapulting India’s aviation market from 9th to 3rd position within a decade. Growing urbanization, robust middle class, increasing affordability and accessibility of air transport and increased global business connectivity, among other things, have contributed to these salubrious projections. Nevertheless, the challenges that lay ahead of the Indian air transport industry are daunting.

This growing demand for air transport has already lead to congestion in the air transport system at the major airports. Airspace and airport congestion not only lead to economic losses but raises many issues related to environment and safety. Increasing air congestion, carbon emissions and high fuel costs are significant impediments in full fructification of this industry. Further, in India, the increasing numbers of passengers have not brought in profits, resulting in the airline industry suffering from chronic accumulated losses as well as capacity constraints due to limited aviation infrastructure (airspace and airports) to meet the demands of increased traffic. Shortage of skilled workforce, chronic delays in existing projects and riskier post 9/11 security scenario are other issues which the air transport industry and its technology development faces in India.
In the civil aviation sector, India has been excessively dependent on imported technologies. The primary thrust of public sector units like HAL, DRDO, BEL and ISRO has been on developing technologies for defence sector. Consequently, despite there being a dedicated agency in National Aeronautical Laboratory (NAL) for developing aerospace technologies, design and aircraft building in the civilian sector, India has remained a laggard in aircraft design and manufacture. However, with the Government’s “Make in India” initiative and opening up the sector for FDI, lot of big industrial houses have entered in the fray. In the last two decades Indian technology companies have made significant progress in providing software engineering services to the global aerospace majors, Indian companies are recognized for their capabilities to meet the very stringent quality requirements of the sector. Almost all the major global aerospace companies have set up engineering and design centers in India, to take advantage of the local talent, and also for the long term business interest.

India has embarked upon a serious technology drive to upgrade its Air Navigation Services (ANS) infrastructure and technologies including radar surveillance systems, reduced separation requirements in performance based airspace design. A satellite based augmentation system for GPS signal, GAGAN will eliminate the need for ground based radio navigation aids which are costly, difficult to maintain, and have limited range.

By 2035, India should aim to garner 5 per cent of global share of the aerospace supply chain. The guiding vision should be of a safe, sustainable and scalable air transport system through development of most efficient technologies available. The roadmap for technological priorities strategize in short term, medium term and long term perspectives, which includes the futuristic technologies like include high speed aircraft, cryogenic planes, pilotless aircraft, stealth technology, new materials like composites, avionics, radar, nano-technology, superior control and other futuristic technologies.

The report makes important recommendations in all these regards and impresses upon the need to prioritize development of manufacturing capabilities and integrate them with the global supply chain. Moreover, the success of this vision depends upon creating an adequate pool of right-skilled workforce, access to technologies through global collaboration, supporting private partnership in downstream technologies, looking for viable PPP models or encouraging public entities in the upstream R&D, long term clarity on regulatory and policy fronts, strong certification capabilities, access to cheaper raw materials, and a well developed manufacturing ecosystem capable of supporting such initiatives.
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ROADWAYS
1.0 INTRODUCTION

Transport is an essential component with which people not just connect with each other, but also progress. To fulfill the increase in demand for safe, reliable, environmental friendly, economical and efficient transport system, road infrastructure becomes crucial. With an increase in types of motor vehicles, there has been a gradual transition from rail-dominated transport to road-dominated transport over last few decades. The share of railways in passenger-km has decreased by ~60%[1]. Transport of passengers and goods is vital to satisfy the mobility needs, which is commensurate with today’s lifestyle characterized by social interactions and reliable goods distribution nationwide. The transportation system of any country works as the backbone of the nation’s economy. Transportation infrastructure needs to be upgraded periodically as per the requirement of the economy. Road transportation system consists of two major segments: Road network, and vehicle systems. Brief overview of evolution and growth in these segments is given in following sections.

1.1 EVOLUTION OF ROAD TRANSPORT SECTOR IN INDIA

Starting from 1960’s, Indian road network has developed in several stages and it is largely influenced by different political, technological, environmental and social factors. Total length of motorable roads in India in 1954 was estimated to be ~353,000 kms, which was meagre for any country of size of India, and its population. In 1985, the total motorable road length increased to 1.77 million kms and 208,938 villages were connected by the new roads[2]. The problems related to urban transport became increasingly complex due to massive increase in road network, increased economic activities on the one hand and shortage of resources on the other hand. Due to unprecedented growth in population and unchecked migration from rural areas to urban areas and metropolitan cities, population pressure increased in urban areas and metropolitan cities.

Today, India has one of the largest road networks in the world aggregating to ~5.23 million kms as of November, 2016. Roadways still remains the dominant mode of transport in India, carrying >75% of total traffic, out of which, road carries >57% freight traffic and >85% passenger traffic[3]. There are several indicators, which are the indicators of development of road infrastructure. These include total road length, passengers carried i.e. billion passenger kilometres (BPKM), vehicles per km of road, passenger cars per 1000 people etc. Road network density of India’s highways is 0.66 km of road per square kilometre of land, which is almost similar to that of the USA (0.65) and greater than China’s (0.16) or Brazil’s (0.20) highway network density[3]. Indian road network face numerous challenges such as overcrowding, congestion, pollution, overloading and poor maintenance of the available infrastructure. 33% of Indian villages still do not have access to all-weather roads. The figure 1.1 shows the evolution of roads as well as the current share of different types of roads in Indian Road network.
Road network needs to be strengthened with new roads, especially connecting remote areas. Last mile connectivity still remains a dream in many areas and needs to be provided. Road quality needs to be improved, especially considering the deterioration in road quality, especially during the rainy seasons. It is suggested that appropriate concrete or hot mix technology should be used to construct good quality roads. India transports >57% of its total freight by road, compared to ~22% in China and ~37% in USA. In contrast, the share of freight transport by railway is ~36%, compared to ~47% in China and ~48% in USA, which is more energy efficient mode of freight transport. Despite the fact that a large part of India’s freight traffic comprises transporting bulk material over long distances, which can be served efficiently by railways and waterways, the share of shipping through waterways is <6%, compared to 30% in China and 14% in USA[5]. With increase in different types of motor vehicles and improvement in road network, there has been a gradual transformation from rail-dominated transport system to a road-dominated transport system in India over past few decades, where the share of railways in terms of passenger-km has shrunk by ~20%. This leads to much higher dependence on fossil fuels and high levels of greenhouse gas (GHG) emissions.

On the basis of mode-wise share, the indicative CO\textsubscript{2} emissions from the major transport modes are given in figure 1.2.
From the figure 1.3, it is clear that the trend towards the use of road transport both passenger and freight is increasing.

In the view of the above, 100,000 kms of National Highway is planned to be constructed in India by 2031, considering 9% annual GDP growth rate. Similarly, ~15,800 kms Expressway road network is required to be constructed by 2020 and ~18,700 kms is envisaged to be constructed by 2031.145,000 kms of state highways are envisaged to be constructed by 2031, whereas 154,522 kms state highways exist now [1].

The road length has increased from 3.70 kms per 1000 persons in 2007-08 to 4.03 kms per 1000 persons in 2011-12, registering a CAGR of 2.2%. In terms of availability of roads per unit area, the road length per 1000 sq. kms increased from 1288.74 kms in 2007-08 to 1480.07 kms in 2011-12 and is now increased to 1660 kms in 2016 (figure 1.4).

Infrastructure facilitates for transportation of people and freight should be provided to give them access to markets, generate employment and create investment opportunities. With growing vehicle population, there is a need to provide matching transport infrastructure, which enables safe, reliable, efficient, and affordable transport. In India, there has been an exponential increase in the number of motorized vehicles in last couple of decades, however the road network has not expanded in sync with this increase.

From the figure 1.4, it is amply clear that in India the rural areas are lagging behind urban areas in terms of accessibility to roads, whereas the urban roads are more congested with only 1.27 kms road per 1000 persons [7].

Infrastructure connectivity is an important link in integrating economic activities and basic services amongst countries in any geographical region and is a prerequisite for future growth of that region. It also opens up rural areas for development and makes cities internationally competitive. Undoubtedly, the evolution of transport will offer many challenges, the biggest of which is providing sustainable transport at the lowest social cost possible. The government policies play a critical role in determining the most likely pathway into the future.
1.2 ROAD NETWORK GLOBALLY

Globally, the road transport sector will grow unabatedly till 2050 (Figure 1.5).

However, it is evident from figure 1.5 that the growth in developing economies is more aggressive compared to developed nations. Indian road transport sector is expected to show a sustained rise of 4.2% till 2030 and 3.8% till 2050. Similarly, the comparison of various countries with reference to the major road indications like road density versus vehicle density are shown in Table 1.1.

**TABLE 1.1 MAJOR ROAD INDICATORS ACROSS SELECT COUNTRIES [9]**

<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>ROAD DENSITY (KM/SQKM)</th>
<th>PAVED ROADS (%)</th>
<th>ROAD LENGTH IN KM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>TOTAL</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>MOTORWAYS</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>NATIONAL HIGHWAY</td>
</tr>
<tr>
<td>BRAZIL</td>
<td>0.19</td>
<td>13.5</td>
<td>15,80,964</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>99,220 (6.28)</td>
</tr>
<tr>
<td>CHINA</td>
<td>0.42</td>
<td>53.50 (2008)</td>
<td>40,08,229</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>74,113 (1.85)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>64,430 (1.61)</td>
</tr>
<tr>
<td>FRANCE</td>
<td>1.87</td>
<td>100.00</td>
<td>10,28,446</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>11,466 (1.11)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8,980 (0.87)</td>
</tr>
<tr>
<td>INDIA</td>
<td>1.48</td>
<td>55.46</td>
<td>48,65,394</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>76,310 (1.58)</td>
</tr>
<tr>
<td>JAPAN</td>
<td>0.89</td>
<td>80.11 (2009)</td>
<td>336,578</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>7,803 (2.32)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>50,810 (15.10)</td>
</tr>
<tr>
<td>KOREA REPUBLIC (2009)</td>
<td>1.05</td>
<td>79.30</td>
<td>104,983</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3,776 (3.60)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>13,189 (13.16)</td>
</tr>
<tr>
<td>RUSSIAN FEDERATION</td>
<td>0.06 (2009)</td>
<td>80.06 (2007)</td>
<td>9,83,000 (2009)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>NA</td>
</tr>
<tr>
<td>SOUTH AFRICA (2001)</td>
<td>0.30</td>
<td>17.30</td>
<td>364,131</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>239 (0.07)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2887 (0.79)</td>
</tr>
<tr>
<td>UNITED KINGDOM</td>
<td>1.72</td>
<td>100.00</td>
<td>4,19,628</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3,673 (0.88)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>49,024 (11.68)</td>
</tr>
<tr>
<td>USA</td>
<td>0.67</td>
<td>10.00</td>
<td>65,45,326</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>75,479 (1.15)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>23,527 (0.36)</td>
</tr>
</tbody>
</table>
The status of various countries globally, with respect to number of vehicles per 1000 people is shown in figure 1.6.

From the above table, USA has highest number of passenger cars (627) on roads per 1000 people. Australia, Germany and UK are at the 2nd, 3rd and 4th position with 556, 517 and 457 cars per 1000 people respectively. While talking about the developing nations, Malaysia, Korea, Mexico are in the top of the list with 325, 276, 191 cars per 1000 people respectively. The global transportation sector is facing unprecedented challenges due to changes in demographics, urbanization, pressure to minimize emissions outside urban centres, congestion, aging transport infrastructure and growth in fuel demand. Regional and global cooperation, unstable global economic situation, and potential technological breakthroughs have a significant impact in the transportation sector.
1.3 COMPOSITION OF VEHICULAR POPULATION IN INDIA

Automotive industry in India is one of the largest industry and is one of the key drivers of the economy. Automotive industry comprises of automotive manufacturing units encompassing commercial vehicles, passenger cars, two-wheelers, three-wheelers, tractors etc., and auto-component manufacturing units. Personalized vehicles (mainly two wheelers and passenger cars) account for more than four-fifth of the motor vehicle population in India compared to their share of little over three-fifths in 1951 (Figure 1.7). The total number of registered motor vehicles on Indian roads increased from 0.3 million in 1951, to 115 million in 2008-09, to 182 million in 2013. This has also led to an increase in the number of registered vehicles from ~25 in 2007-08 to ~33 in 2011-12 per km of road, further adding to congestion.

**FIG 1.7 NUMBER OF REGISTERED VEHICLES IN INDIA (2013)[10]** (IN 1,000)

The traffic in Indian cities has mixed transport modes. There are various modes of road transport in India including 2-wheelers, Cars, SUVs, Jeeps, Buses, Mini Vans, Buses, Vans etc. Urban road transport is increasing significantly per capita however availability of road space per vehicle is declining rapidly, adding to urban congestion woes. As on March 2011, two-wheelers account for the largest share (72%) amongst the total registered motor vehicles of the country, followed by Cars, Jeeps and Taxis (14%), other vehicles (8%), goods vehicles (5%) and buses (1%) (Figure 1.8).

Inadequate and inefficient public transport as well as grossly inadequate infrastructure is some of the key reasons for sharp imbalance in modal split of vehicle population, which has led to sharp spurt in demand for private vehicles. Modal share of transport in Indian cities is given in figure 1.9.

Increases in car ownership, driven by rising household incomes, increasing population and urbanization have catalysed the per capita travel exponentially. The number and size of urban cities has also increased transport demand and the distance travelled per capita. Motorized two-wheelers have been the most rapidly growing transport mode, with an average of 17% annual growth rate between 2001 - 2015. This rate is higher than 15% annual average growth rate for all types of motorized vehicles.

The lag in investment in the transport infrastructure has a detrimental effect on the booming car ownership, because available road space per car is continuously shrinking. Congestion leads to higher fuel use per km travelled, leading to significantly higher emissions.
Urban population in India will reach to 40% of the total populations by 2030 from 30% at present, fuelling the demand for explosive growth on 2-wheelers and passenger cars segments. It is estimated that the number of vehicles will increase to about 600 million by 2030 [12]. Therefore the demand for road infrastructure and urban road network planning also needs to be proportionally increased. In contrast to personalized mode, the share of buses in total registered vehicles has declined from 11.1% in 1951 to a mere 1.3% in 2009, although the absolute numbers have increased phenomenally. Similarly, the share of goods vehicles, which stands at 5.3%, has shrunk since 1951. The erosion in % share of buses in the vehicle population to ~1.3% reflects relatively slower growth in public passenger bus transport services and the public transport systems in Indian cities.

1.4 HISTORY AND EVOLUTION OF INDIAN TRANSPORTATION SECTOR

Transport sector in India is an important and integral part of national economy. Since the economic liberalization of India in 1990’s, development of transport infrastructure has progressed at a rapid pace. Today, there is a wide variety of modes of transport by land, water and air. However, India’s relatively low GDP per capita has transformed into non-uniform access to these modes of transport. Motor vehicle penetration per 1000 person is very low by international standards. In addition, only ~10% of Indian households own a motorcycle. Public transport still remains the primary mode of transport for large section of population, and India’s public transport systems remains amongst the most heavily used transport systems in the world. Despite on-going improvements in the sector in last few decades, several aspects of the transport sector are still riddled with problems due to lack of investment in less economically active regions of the country. The demand for transport infrastructure and services has been galloping at a rate of ~10% per year however the current infrastructure and investments are unable to meet these demands. According to recent estimates by Goldman Sachs, India would require to spend US$1.7 trillion on road network related infrastructure projects over the next decade to boost economic growth. Although the number of vehicles are increasing continuously but the increment in motorization index is still lower compared to other countries. Possible reason for this may be relatively faster growth in Indian population. Comparison of total vehicle and motorization index for China, Asean countries with India is shown in figure 1.10
The automobile industry in India is rapidly growing with an annual production of over 4.6 million vehicles, and vehicle volumes are expected to rise rapidly in future. Evolution and major growth of automotive sector in India can be divided into four phases. These phases are categorized on the basis of technology, duration and market popularity.
This period was ended in late 80's when car was a measure of status and very few people could afford a car. At that time, there was no awareness about car technology and maintenance.

Post 2000, growing middle class power and changing pattern of consumerism were two main factors behind the rapid growth of automotive industry in India. Increasing urbanization and income of youths have further enhanced growth of car industry in India. Indian car industry has been doubled in last 10 years. Important achievements of this phase include a booming small car segment, use of alternate fuels, introduction of hybrid cars, changing approach towards customer service and new car technologies.
This period was ended in late 80’s when car was a measure of status symbol and very few people could afford car. At that time, there was no awareness about car technology and maintenance.

Opening of foreign players in the Indian market to build the foundation of next stage of evolution for automotive industry was the most important event of this phase. In this phase, initial changes in technology and customer preferences were taken care by foreign automotive industries. Due to these facts many foreign companies including Honda City were found game changers in Indian automotive market.

Phase 4- Mid 2000’s to 2015
Fast paced growth due to rise of middle class group
1.4.1 EVOLUTION OF TRANSPORT TECHNOLOGIES

Automotive technology refers to the technologies incorporated in vehicles for their design and development. These technologies are essential for continuous development and changes in the existing vehicles. With rapidly increasing demand as well as expectations of consumers towards higher safety standards, low-carbon future embodied more aggressively in government’s fuel economy standards and stringent emissions norms. This has accelerated the pace of vehicle technology changes. When considering changes in automotive technology that support the ‘greening’ of transportation sector, most people think about advanced powertrains— including hybrids, plug-in hybrids, battery electric, advanced IC engines and advanced diesels. This is followed by alternative fuels, including renewables such as biofuels, solar energy and hydrogen. Sector-wise modifications in automotive technology from evolution to current status are summarized in the following sections.

(i) Automotive Engines: Most important changes which have taken place in the automotive sector in India pertain to development of advanced engine technology. In gasoline cars, carburetor engines have been replaced by the Multi Point Port Fuel Injection (MPFI) engines. This technology is capable of complying with the stringent automotive emission norms of India and manages to extract maximum benefit of fuel economy. Similarly, diesel vehicles have undergone dramatic changes in the last decade with the advent of Common Rail Direct Injection (CRDI) technology. CRDI technology offers unprecedented flexibility, which was never available to conventional diesel engines, and delivered 25% higher power output compared to baseline conventional direct injection diesel engines, a soundless engine with enviable pickup and acceleration, and a superb fuel economy for a mid-sized diesel car. Currently, extensive research is being undertaken for the development of advanced combustion concepts such as Homogeneous Charge Compression Ignition (HCCI), Gasoline Direct Injection (GDI) etc., which are expected to further improve the combustion efficiency and performance characteristics of current generation automotive engines.

(ii) Automotive Fuels: Starting from 1960’s, a large number of changes have been made to the automotive fuel specifications. Leaded gasoline was used to control engine knocking however it was discontinued after the recognition of harmful effects of lead in the ambient air. High sulphur content of the fuel was another major issue, which was responsible for harmful engine-out emissions. The sulphur levels were reduced gradually and the petroleum companies have now started producing ultra-low sulphur fuels to control particulate emissions from vehicles. Due to rapidly depleting petroleum reserves globally, it is essential to develop and promote alternate fuels and technologies, which are environmentally benign and sustainable. Research is being undertaken to develop several alternate fuels such as biodiesel, and alcohols etc. Engine technologies are also being developed for using gaseous alternate fuels such as CNG, LPG for last six decades and these technologies have now matured enough to be commercialised in India. R&D for using hydrogen as an automotive fuel is being undertaken expeditiously in India and several organizations are working on various aspects of commercialisation of hydrogen/ its utilisation technologies and infrastructure development.

(iii) Emission Standards and Control Strategies: An effective control on the emission of harmful pollutants like Oxides of Nitrogen (NOx), particulate matter (PM)/ soot, Carbon Monoxide (CO) or volatile hydrocarbons is essential in order to conserve the environment and preserve human health. Large number of exhaust gas after treatment devices such as Selective Catalytic Reduction (SCR), NOx Storage Catalyst (NSC), Three Way Catalyst (TWC), Diesel Particulate Filter (DPF) etc. along with advanced in-cylinder combustion control techniques such as HCCI, PCCI, LTC are being developed and deployed, as per the requirements of emission norms.

(iv) Transmission and Suspension Systems: Transmission system of vehicles has improved significantly since the advent of Indian automotive industry. Initially, vehicles were equipped with manual transmission system with a small range of variations. Today, the transmission systems have been completely modified and automated transmission systems
are introduced in Indian market. Automatic transmission with higher gear ratios and more sophisticated electronic controls are crucial for improving the fuel economy. Adding additional gears help keep the engine operation in a speed range, where it delivers superior performance at the best economy. An 8-speed automatic transmission can deliver up to 11% better fuel economy compared to a conventional 6-speed transmission, depending on engine, vehicle and drive-axle gearing. The suspension system of a vehicle consists of springs, shock absorbers and linkages. These systems together connect the vehicle to its wheels. However, the main function of the suspension system remains to minimize jerks and to provide a smooth journey to its occupants. Suspension system technologies have also evolved in last few decades and new generation technology is deployed to improve drive comfort to the vehicle occupants.

(v) Material: Changes in material selection and forming processes were aimed at producing lightweight, safer and greener vehicles, which require lesser fuel for propulsion. Advanced, lightweight, strong materials used in the vehicle body are the important ones among these materials. They help in weight reduction of the vehicle and enhance passenger safety. Carbon fiber reinforced polymer composites have the potential to reduce component weight by >60% however there are significant technical and cost barriers to their widespread introduction in vehicles. Application of aluminium within automotive design include hoods and panels, power-train components, and even entire vehicle body-in-white (BIW) structures. There are several barriers to the increased use of Al in vehicle weight reduction applications such as material cost, room temperature formability, and limitations in existing manufacturing infrastructure. Conventional iron and steel alloys are prominent in existing vehicle architectures, making up to >70% of the weight of a vehicle. Despite relatively high density of iron based materials, the exceptional strength and ductility of advanced steels offers potential for efficient structural designs and reduced weight. Application of a new generation of advanced high strength steels (AHSS) has the potential to reduce component weight by >25%, particularly in strength limited designs.

(vi) Design and Aerodynamics: Vehicle design and aerodynamics include three interacting flow fields namely; flow past vehicle body, flow past vehicle components (wheels, heat exchanger, brakes and wind-shield) and flows in the passenger compartment. Aerodynamics of commercial vehicles has evolved over many years. Basic objectives of streamlined body include reduction of fuel consumption, more favourable comfort characteristics and improvements in driving characteristics such as stability, handling, and traffic safety.

(vii) Control and Electronics: Today’s cars contain more computer chips and lines of software code than the first vehicles launched into space. Increasing electronics, software, controls, and technology content enables many fuel-saving technologies as well navigation assistance to reduce idle time and traffic congestion. Beside these sensors, actuators and controls are used to optimize vehicle performance for best fuel economy. This category includes innovations in the field of
electronic components (semiconductors, sensors), electronic control units (e.g., body electronics, brake control systems and engine management) and other system control units.

1.5 DRIVERS FOR GROWTH IN ROAD TRANSPORT SECTOR

For a developing country like India, a national road transportation system is required, which can economically move anyone anything, anywhere, anytime, on time without fatalities and injuries. For the growth of the economy, good living standard, independence of its citizens as well as functional and efficient transportation system should be in place, which leads to reduce dependence on imported energy and is environment friendly too. A comparison of Indian road transport scenario, BPKMVs BTKM is given in figure 1.11.

Road freight in India has increased since its 1950–51 level of 6 BTKMs to an estimated 1,250 BTKMs in 2011–12, witnessing a CAGR of 9.14% during this period. Over the next five-year period, from 2012–13 to 2016–17, assuming GDP growth of 8%, road freight is expected to grow at a CAGR of 9.6%. Road transport segment has not traditionally seen significant investments in manpower development as compared to other segments such as rail and air. This has resulted in skill gaps among the existing set of personnel, particularly among the truck drivers. Assuming that this rate of growth would continue in the future, the projected freight traffic up to 2017 is shown in figure 1.12.

In ‘BAU’ scenario, the projection of passenger traffic is based on the pattern of growth of passenger traffic between 1980-81 and 2010-11. The rate of growth of passenger traffic during this period was ~8.8% per annum. It may be noted here, that the growth rates of per capita income, measured by per capita Net National Product (NNP), population and urban population during 1980-81 to 2010-11 were 4.9%, 1.9% and 2.9%, respectively [14].

The passenger traffic measured was projected to grow at 7.2% per annum during 2012 to 2017. Based on BAU and regression analysis, BPKM for next five years is shown in figure 1.13.
The basic drivers for the growth in road transport sector in India are as follows:

(i) Rising population: India is already one of the most densely populated countries in the world. By 2035, this situation will have been exacerbated by a mammoth rise in population, which is forecasted to reach 146 crore by 2035[16].

(ii) Income inequality: Income inequalities are growing e.g. between north and south, rural and urban communities and indeed within many towns and cities across the nation. These inequalities enhance the vehicle purchasing power of affluent class, which affects the road transportation system. Even middle and low income group population is interested in purchasing two wheelers and low end cars.

(iii) Young population: The number of people aged between 14 to 64 years is expected to increase, resulting in a higher ratio of workers to the dependants, leading to higher savings. This would translate into increased ability for vehicle ownership in next few years. This will greatly push up the need of an efficient transportation system.

(iv) Demand stability: The passenger vehicle industry is also benefitting from India’s favourable demographic profile, which is reflected by its very young population (50% population under the age of 25), steadily improving dependency ratio, growing urbanization and trend towards smaller nuclear families. In addition to this rising per capita GDP level is also resulting in vehicle affordability.

(v) Higher demand in future: While new forces have emerged that may impact the travel demand in future, the department of statistics forecasts the road travel will continue to increase by ~30% between 2011 to 2035. [17].

(vi) Public transport on the up: The historic trend of falling public transport patronage has ceased in many cities in recent years due to introduction of modern metro system. In many metropolitan cities >35% commuters have already shifted their mode from road to rail transport.

(vii) Cost of energy: Globally, Shell and BP forecast that energy demand will increase by 30-40% by 2035. Oil and gas prices are expected to continue to rise substantially, although it is generally considered that sufficient resources shall still be available but the rapid increase in prices is changing the scenario that generates the need of transformation in road transportation sector.

(viii) Cost of travel in real terms: Bus fares and the cost of driving (excluding car purchase price) have both increased at a very fast pace. However, when car purchase prices are taken into account, the real costs of motoring actually falls significantly. These two factors influence the car purchasing tendency hence affects the road transport. This also increases the total car travel distance per person per year.

(ix) Road congestion costs: Road congestion is already costing the economy dearly. This not only affects the passengers but also affects the industrial production hence directly affects nation’s economy. Due to rapid growth in vehicle numbers, this factor enforces for innovative strategies to reduce congestion.

1.6 Guiding Principles of an Efficient Transportation System

The overarching concept of sustainable transport involves moving people, goods and information in a way, which reduces the impact on environment, economy, society as well as includes using energy-efficient transport modes, improves transport choices, uses cleaner fuels and technologies embedded with using information and communications technologies to reduce or replace physical travel which will lead to a sustainable transport system. Many of these approaches are included in the issues identified above. The development of a sustainable land transport system for India will also involve reference to a range of indicators for sustainable transport which includes fixed and flexible urban transport routes, public transport priority, private motorized vehicle ownership, accessibility of public transport vehicles and infrastructure, passengers carried by public transport, investment in public transport, road safety, fuel consumption, and pollution reduction technologies in public transport fleet. It will be important to develop the framework and sources of data, by which the road transport system can benchmark its progress towards becoming a sustainable...
transport system. The efficient transport system should comply with the followings:
• reduce the impact on environment by reducing GHG emissions
• appropriate designing of transport systems which encourage walking, cycling, promoting use of public transport
• accessibility of all categories of people
• safe, secure and comfortable

In order to provide these capabilities in future, the road transport sector needs to be:
• Integrated providing citizens and businesses with seamless, convenient, safe and secure services, anywhere in the India and in the world.
• Intermodal functioning as one seamless transportation system that provides convenient connections and transfer facilities in and among all transport modes comfortably, efficiently and economically.
• Inclusive providing safe, reliable, affordable, and convenient service to all citizens, wherever they live, work, travel or ship goods.
• Intelligent enabling the integration and transformation of existing systems into a more efficient international, inter-modal, and inclusive network.
• Innovative creating an environment that will enable India to transform newer technologies, concepts, and ideas into newer transportation products, processes and services quickly and in a cost-effective manner.

REFERENCES

1. “National Transport Development Policy Committee” NTDPC, Vol. 03, Part 1, Chapter 2; Ministry of Road Transport and Highways, 2013.
2.0 INTRODUCTION
Various studies showed that the quality and robustness of road transport infrastructure networks greatly impact economic growth, reduce income inequalities and alleviate poverty. Road connectivity has improved across most parts in India, however significant further improvements are yet to be made in the country for fuelling economy growth. Enhancing road transportation infrastructure in India remains an insurmountable challenge as of now. Infrastructure connectivity deals with integration of road networks at various railheads, major river ports and better access to sea ports via appropriate highways. Regional road network infrastructure projects are usually more complicated and expensive than typical national road infrastructure projects, particularly in the hilly and inaccessible terrains of the country. Intermodal connectivity therefore plays a vital role in seamless movement of people, and goods from one place to another.

2.1 INTERMODAL AND MULTIMODAL CONNECTIVITY
Multi Modal Transportation System (MMTS) exploits coordinated and judicious use of multiple modes of transport for faster, safer, and more comfortable movement of people, especially in urban areas. It provides convenient and economical inter-connection amongst various transport modes to provide entire journey from origin to destination in a comfortable and cost-effective manner. MMTS is traditionally characterized by high capacity, accessible and appropriately located nodes, which integrate various transport modes. This can be achieved by better synchronization amongst various transport modes and provides superior and efficient service.
In MMTS, each mode of transport is combined which yields the most economical transportation for the supply chain. Efficiency is the prime rationale for intermodal transport, but accessibility and efficiency remain the prime reasons for using two or more transport modes. Most exports require trucks, or railcars for pick-up and delivery at some point in the supply chain in any economy. Intermodal transportation system competes with conventional road transport in terms of costs and time. A rail-barge intermodal transport system would have lower cost than an all rail freight movement. Shipping of value-added goods is more or less reliable but transit time is higher in intermodal transport. Hence, potential time savings in intermodal transport remains a key competitive issue. Figure 2.1 shows a typical intermodal transport system.

The level of connectivity controls reliability and transit time. Any impediment that slows or halts the flow of traffic creates a bottleneck. The symptoms of bottlenecks are usually congestion, slowdown of vehicular movement, queue formation or shipping delays, which not only have negative impact on economy but also causes environmental pollution. Bottlenecks may be due to lack of infrastructure or due to unfavourable regulatory causes and in some cases, dysfunctional supply chain.

Operation of multimodal system is complex. Systems integration with new technologies that support data acquisition and information management is the key requirement. These systems also integrate hardware and software components into a multifunctional platform, specifically designed for planning and monitoring of multimodal transport. Components of MMTS is given in Figure 2.2.

Connectivity deals with all levels of transit service coverage, thus integrating routes, schedules, socio-economic stratas, demographics and patterns of spatial activity. The objective of using connectivity as an indicator is to quantify and evaluate transit services in terms of prioritizing transit locations and assessing its effectiveness and efficiency. A typical intermodal connectivity for public transport is shown in Figure 2.3. In a typical urban centre, commuters can drive and park at the nearest bus station to ride a bus and then change over to a metro at a suitable transit point. This intermodal public transport framework is deployed in several developed countries. In India, efforts are made to establish such multimodal connectivity in Delhi and Hyderabad.

2.1.1 MODAL SHIFTS IN PUBLIC TRANSPORT
An important alternative to using cars, scooters or other personalized vehicles is public transport. Major cities globally are emphasizing on raising the share of public transport. India has made a commitment to reducing GHG emissions in INDC report to the tune of 32 – 35% per unit GDP by 2030 w.r.t. the base year 2005. GHG emission issue has also been discussed extensively in the Climate Change Conference of Parties.
COP-21, Paris and in COP-22, Marrakech. Shifting the public transport could be one of the implementation strategies to achieve the above target. Several cities have formulated investment plans and expansion of existing lines, changes in bus/tram fleet, interconnectivity (park and ride). Some cities have a very high share of public transport. In others, public transport plays a relatively minor role and is an equal alternative to car usage. In some cities, there are well developed existing networks, while others are currently under expansion plans. A broad range of measures are developed to improve public transport systems and promote the use of public transport. Several lines were expanded, the frequency of services were increased, enhanced information flow and accessibility was ensured. New travel modes such as ‘light metro’ or monorail have been implemented in several cities worldwide. Information service to the citizens has been improved over a wide range of media about the real-time schedule of the services.

2.1.2 INTERMODAL CONNECTIVITY OF RAIL, ROAD AND PORTS

The concept of connectivity via the development of regional infrastructure to link one country to another is not new to Asia. In India, poor rail and road connectivity affects cargo movement and concept of intermodal transport is evolving rather slowly. There is great scope for improvement in rail-road connectivity with major ports. Maritime infrastructure greatly facilitates international trade and economic growth. Therefore a major port performance indicator is intermodal connectivity. Intermodal connectivity is relevant, because many ports can handle a larger share of the volumes with the seamless assistance of intermodal transport methodology. A higher share of intermodal transport requires better connectivity between ports and intermodal terminals in the hinterland. Sea ports in India handle roughly 70% of all container volumes. Cargo handled at the 12 major ports in India has increased to > 400 million tonnes. Government of India has emphasized on development and modernization of the port infrastructure, in order to become globally competitive. Currently, ports are unable to handle additional traffic because of slow evacuation of cargoes from the ports due to inferior intermodal connectivity. Therefore despite of having adequate capacity and modern cargo handling facilities and infrastructure, ports are unable to ensure a quick ship movement, which undermines the competitiveness of Indian ports in global arena. Therefore, it is essential that intermodal connectivity of major ports with the hinterland is supplemented on a priority basis to ensure sustained economic growth and bottlenecks in freight movement is minimised.

2.2 INTELLIGENT TRANSPORT SYSTEM

Intelligent Transport System (ITS) is defined as ‘the use of modern communications, computer and control technologies and systems to improve mobility and transportation productivity, enhance safety, maximise utility of transportation facilities, save energy and protect the environment’. ITS is a term used to refer to several inter-dependent transport modes and road technologies, and offers to check congestion, air pollution and road safety using intelligent communication systems. Information and communication technology (ICT) plays an important role in revolutionizing the ITS. Intelligence can be embedded at all levels of the systems e.g., in the vehicles and its subsystems, in the surrounding infrastructure, in the energy supply, in the traffic management systems and in the services delivered by the system. ITS is not restricted to road transport alone, but also plays an important role for other modes of transport like rail, water, air and MMTS. Internet of Things (IoT) makes these communications amongst different sub-system components possible, thereby enabling a new realm of optimization and automation.

While highway capacity investments can deliver a benefit-cost ratio of 2.7 to 1, ITS technologies can substantially improve this ratio to 9 to 1. ITS has demonstrated dramatic improvements in traffic management and road safety in several countries of the world. Therefore for ITS, the benefits far outweigh the investment hence its implementation in India is desirable and inevitable.

ITS brings together system users, vehicles and the infrastructure into one integrated system, and enables these elements to exchange information for better management and use of available resources via (a) Smooth flow of traffic and improved mobility on congested corridors, while making them safer and efficient, and (b) Improving intermodal transfers, efficiency and reliability of transport.
In India, few applications of ITS have already been introduced, mostly in metropolitan cities e.g. ITS for parking management, electronic tolls, tracking of public transport etc. Intelligent transport systems, which include GPS navigation systems, intelligent roads, sensor based safety systems, vehicle tracking, electronic toll collection, crash avoidance systems, high speed corridors, bus and train rapid transit systems will be required. A fully developed ITS application connecting various applications and areas and communicating seamlessly is absent as of now in India and we have to take some solid steps in this direction.

2.2.1 Intelligent Roads
The intelligent roads aim at addressing the needs of road users by improving driver’s awareness of sudden changes in road conditions, information on pavement safety and real-time traffic information based on traffic data and safety status. With increasing demand for freight transport, damaged roads worsen. New approaches are essential to increase the capacity and improve the road maintenance by adding intelligence infrastructure to the existing road networks. An innovative integration of existing sensors and communication technologies with road infrastructure is one way of reaching the twin goal of increased safety and enhanced capacity. For a relatively small cost, significant ‘added value’ can be obtained from the existing infrastructure, thereby achieving a cost effective solution. This technology can be used in India in future and the country need to make some serious investments in this area to develop suitable infrastructure. A typical intelligent road is shown in figure 2.4.
The future of intelligent transportation system relies on super-intelligent vehicles, infrastructure, control systems, planning, and driver’s acceptability. Legislation would play a key role in ensuring and encouraging use of such intelligent, futuristic technologies in India e.g. communication among vehicles or between a vehicle and the infrastructure would happen only when it is legalised in the country. This infrastructure development will require investments, both from public and private sector and special purpose bodies will be required to be constituted in order to implement these projects in fast track mode. Intelligent transport systems will improve vehicle safety and contribute to resolving traffic management issues in India. Table 2.1 lists some of the ITS Technologies required to be used in India.

**TABLE 2.1  ITS TECHNOLOGIES FOR ROAD TRANSPORT IN INDIA**

<table>
<thead>
<tr>
<th>NAME OF TECHNOLOGY</th>
<th>DESCRIPTION</th>
<th>REMARKS</th>
<th>INVESTMENT REQUIRED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic Management</td>
<td>Consistent real-time traffic information system for all modes of transport</td>
<td>Technology used for all vehicles</td>
<td>Investment for required hardware and software</td>
</tr>
<tr>
<td>Freight Information systems</td>
<td>Information related to logistics of freight operations in India and its tracking</td>
<td>Technology used for LCVs and HCVs</td>
<td>Investment for required hardware and software</td>
</tr>
<tr>
<td>Electronic Toll Collection</td>
<td>Efficient and automated collection of tolls by Electronic Toll Collection (ETC) plazas leading to less holdup of vehicles and reduction in travel time</td>
<td>Technology used for all vehicles</td>
<td>Investment for required hardware and software</td>
</tr>
<tr>
<td>Vehicle to Infrastructure</td>
<td>The smart and efficient transfer of information between vehicle and infrastructure setup using in-vehicle telematics</td>
<td>Technology proposed for All Vehicles</td>
<td>Investment for required hardware and software</td>
</tr>
<tr>
<td>Communication</td>
<td>The integration of technologies for information transfer between vehicles using open in-vehicle telematics platform</td>
<td>Technology proposed for All Vehicles</td>
<td>Investment for required hardware and software</td>
</tr>
<tr>
<td>Vehicle to vehicle Communication</td>
<td>Restriction of speeding on highways through speed tracking of vehicles</td>
<td>Used for some passenger cars and SUVs</td>
<td>Investment for required hardware and software</td>
</tr>
<tr>
<td>Intelligent Speed Management</td>
<td>Tracking of accidents, maintaining a record and quick delivery of first aid to victims</td>
<td>Used for all vehicles</td>
<td>Investment for required hardware and software</td>
</tr>
<tr>
<td>Incident detection</td>
<td>Tracking of movement of Dangerous goods throughout all the modes by ensuring multimodal interconnection</td>
<td>Technology proposed for CVs</td>
<td>Investment for required hardware and software</td>
</tr>
<tr>
<td>Hazardous goods Tracking</td>
<td>Navigation aids to drivers based on satellite systems for safe and efficient travel</td>
<td>Technology applicable to all vehicles</td>
<td>Investment for required hardware and software</td>
</tr>
</tbody>
</table>
2.3 Inspection, Maintenance and Certification

The vehicle inspection, maintenance and certification program is an effective tool to monitor the health of vehicles as well as for improvement of the roadworthiness of the in-use vehicles. As India continues with setting more and more stringent emissions norms for new vehicles, this will only have a lasting effect if accompanied by a reliable system of maintenance. One way could be to enforce the mandatory inspections and to include a comprehensive emission testing. A nationwide, reliable system of inspection and maintenance would also be an important measure to control emissions from the fleet of younger vehicles that will still be in use for several years. Effect of vehicle life and maintenance on emissions is depicted in fig 2.6. Based on 2012 transport vehicle data of 160 million vehicles and considering average CAGR, it is estimated that 300 light-duty and 320 heavy-duty I and M centres will be required in India by 2020. The current inspection practice definitely needs to be made more comprehensive, for instance including trucks and buses. This requires a higher training of the people implementing it as much as it requires infrastructure and adequate financial, political and public support.

Less maintenance and a higher deterioration across the whole fleet significantly affects the resulting total emissions: NOx emissions may increase by 19%, while CO emissions might increase by as much as 68%. Inversely, assuming as low emission factors as CPCB (2000) for Delhi, i.e. a much higher level of maintenance in the whole country, would result in −20% lower total NOx and −51% lower CO emissions [4]. The overall variation in emissions is large as the vehicle emission factors are not constrained by anything, notably not by the fuel consumed. The high variations in CO and PM are due to large differences in the emission factors of vehicles until and after 2000, the first year of the more stringent EURO I equivalent emission norms; this concerns primarily M2W and M3W for CO and HDT and buses for PM. Similarly, higher mileage of old vehicles also result in relatively higher emissions as −10% higher CO, −4% HC, −2% NOx and −5% PM.

Long-life roads and more durable structures will both reduce the maintenance costs of the road network and reduce traffic disruptions. Incident clearance will be quicker; aided by high-speed data gathering to record the ‘scene’ and to provide legal evidence, wherever and whenever it is needed. Temporary structures using new light-weight materials can be deployed to relieve congestion during maintenance and reduce the need for diversions. Lack of maintenance of roads is a major issue in India. Provision for maintenance of the National Highways comes from the non-plan budget and typically only one-third the required amount is provided. The introduction of toll roads on a ‘BOT’ basis has helped ensure maintenance. The involvement of panchayats and other PRI agencies to ensure the maintenance of rural roads may be a desirable initiative. These and other alternative mechanisms should be explored to strengthen maintenance arrangements for the road network in the length and breadth of the country. Research agenda for ‘I AND ‘M’ is shown in table 2.2.

FIG 2.6  EFFECT OF VEHICLE LIFE AND MAINTENANCE ON EMISSIONS [4]
TABLE 2.2 RESEARCH AGENDA FOR ‘I’ AND ‘M’

<table>
<thead>
<tr>
<th>Short Term (1-5 Years)</th>
<th>Medium Term (5-10 Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public transport services and freight logistics should be highly optimized and real time responsive.</td>
<td></td>
</tr>
<tr>
<td>Urban/ Suburban hubs should be developed and connected to main corridors.</td>
<td></td>
</tr>
<tr>
<td>Intelligent deployment of road space in response to demand (tidal systems, lane allocation, and lightweight temporary structures in the areas of dense development).</td>
<td></td>
</tr>
<tr>
<td>Intelligent monitoring of roads and structures.</td>
<td></td>
</tr>
<tr>
<td>Electronic means of access (tele-working etc.) to enhance and complement the travel, and provide partial substitution.</td>
<td></td>
</tr>
<tr>
<td>Construction of long-life roads and more durable structures.</td>
<td></td>
</tr>
<tr>
<td>Investment for construction/ maintenance on the basis of whole-life costs and low maintenance disruption.</td>
<td></td>
</tr>
<tr>
<td>Minimized “down time” for maintenance and accident clearance.</td>
<td></td>
</tr>
</tbody>
</table>

REFERENCES

3.0 SAFETY AND SECURITY ISSUES

3.1 INTRODUCTION

Increase in the number of vehicles and lower road density are the key factors responsible for increase in number of road accidents every year in India. India has maximum road fatalities in the world, which are continuously increasing year on year. Figure 3.1 shows that road fatalities in India increased from 1.32 Lakh in 2010 to 1.37 Lakh in 2013.

The Compound Annual Growth Rate (CAGR) of number of road accidents and persons injured in road accident in the country during the decade 1994-2003 and 2004-2013 has decreased from 1.0% to 0.6% and from 1.5% to 0.3% respectively. This was particularly severe because 53.1% of road accident victims were in the age group of 25 to 65 years in 2013, with pedestrians, bicyclists and 2/3-wheelers, comprising the most unprotected road users, accounting for ~40% of the fatalities (Figure 3.2).

According to the Times of India dated 8th Oct, 2012, with 1% of total global vehicle population in the country, India accounts for 10% of vehicular accidental deaths. Every 6th road accident in the world takes place in India. According to a recent WHO report, one person is killed every 3.7 minutes in a road accident in India and one accident takes place every minute. Figure 3.3 shows fatalities due to accidents involving various types of vehicles.

**FIG 3.2**
ROAD ACCIDENTS VICTIMS
(OTHER THAN DRIVERS) BY AGE GROUP[1]

**FIG 3.1**
TOTAL NUMBER OF ROAD ACCIDENTS, PERSONS KILLED AND PERSONS INJURED DURING 2003-2013 [1]

**FIGURES IN PARANTHESES: PERCENTAGE OF PERSONS KILLED IN TOTAL ROAD ACCIDENTS**

<table>
<thead>
<tr>
<th>AGE GROUP</th>
<th>NUMBER</th>
<th>PERCENTAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-14</td>
<td>5,937</td>
<td>4.1</td>
</tr>
<tr>
<td>14-25</td>
<td>48,426</td>
<td>33.1</td>
</tr>
<tr>
<td>25-35</td>
<td>30,656</td>
<td>21.0</td>
</tr>
<tr>
<td>35-45</td>
<td>26,046</td>
<td>17.8</td>
</tr>
<tr>
<td>45-65</td>
<td>26,784</td>
<td>18.3</td>
</tr>
<tr>
<td>65+</td>
<td>4,380</td>
<td>3.0</td>
</tr>
<tr>
<td>UNKNOWN</td>
<td>3,910</td>
<td>2.7</td>
</tr>
</tbody>
</table>

*FIG 3.2 ROAD ACCIDENTS VICTIMS (OTHER THAN DRIVERS) BY AGE GROUP[1]*

*FIG 3.1 TOTAL NUMBER OF ROAD ACCIDENTS, PERSONS KILLED AND PERSONS INJURED DURING 2003-2013 [1]*
From this figure, it is clear that the percentage share of accidents by two wheelers, cars and trucks are more than the other modes of transport put together. This is attributed partly to an increase in number of vehicles on the road. India has twice the number of accidental deaths compared to US (18.9 and 10.4 deaths per 1 lakh people respectively). The figure is all the more appalling when it is computed for 1 lakh motor vehicles, which indicates 134 deaths in India against 15 in the US. Around 1.5 lakh people die in road accidents every year in India, compared to 33,000 in the US as specified in the WHO vehicle safety report 2013. While the population of India is increased by 17.64% over the past ten years, the number of licensed vehicles increased by 132% over the same period [2].

3.2 CURRENT SAFETY TRENDS IN GLOBAL ROAD TRANSPORT

Road traffic safety refers to methods and measures undertaken for reducing the risk of a road network user being killed or seriously injured. The users of a road include pedestrians, cyclists, motorists and passengers of public transport, mainly buses and trams. Road traffic crashes are one of the world’s largest public health and safety issue. According to WHO report 2013, more than a million people are killed on the roads worldwide each year and 50 million people are injured in traffic accidents on the roads. Road accidents are the leading cause of death among children of 10 – 19 years age [2]. The report also noted that the problem was most severe in developing countries and that simple prevention measures could halve the number of deaths. The standard measures
used in assessing road safety interventions are fatalities and Killed or Seriously Injured (KSI) rates, usually per billion (10^9) passenger km. Vehicle speed within the human tolerances for serious injury and death is a key goal of modern road design because impact speed affects the severity of the injury to both, the occupants and the pedestrians. For occupants, probability of death of drivers in multi-vehicle accidents increases as the fourth power of the impact speed. Injuries are also caused by sudden, severe acceleration (or deceleration), but these are difficult to measure. Crash reconstruction techniques can be used to estimate vehicle speeds before a crash. Figure 3.4 shows the current global safety trends as number of fatalities per lakh population and number of fatalities per lakh vehicle respectively. According to this report, India has maximum number of fatalities per lakh vehicle (211.8) however third highest in fatalities per lakh population (19.9).

### 3.3 FUTURE SAFETY TRENDS IN GLOBAL ROAD TRANSPORT

Developed countries have adopted an ambitious Road Safety Program, which aims to cut road deaths severely by 2020. EU has set a target of less than 20000 road fatalities by 2020 (Figure 3.5).

The EU program sets out a mix of initiatives, at pan-European and national level, focusing on improving vehicle safety, the safety of infrastructure and road users’ behavior. Initiatives proposed in the “European Road Safety Policy Orientations” range from setting higher standards for vehicle safety, to improving the training of road users, and increasing the enforcement of road rules. Some of the safety features used are: (1) Limited access from properties and local roads to highways, (2) Grade separated junctions, (3) Median dividers between opposite-direction traffic to reduce likelihood of head-on collisions, (4) Removing roadside obstacles, (5) Prohibition of more vulnerable road users and slower vehicles, (6) Placements of energy attenuation devices (e.g. guard rails, wide grassy areas, sand barrels), and (7) Eliminating road toll booths. In addition, focus is being given on improving safety measures for vehicles, driver training, development of intelligent roads and vehicles and strict law enforcement.

### 3.4 TRANSPORT SAFETY SCENARIO IN INDIA

A noticeable expansion in vehicular transport in the country, particularly in goods vehicles was observed in between 1940’s and 1960’s. The number of goods vehicles in undivided India (excluding princely states) increased from 12,397 in 1938-39 to about 160,000 in 1960-61. This growth generates the need of effective traffic planning to control and regulate these vehicles plying across the length and width of the country. In 1960’s, according to the calculations presented in the Preliminary Report of the Committee on Transport Policy and Coordination, the increase in freight traffic by road was expected roughly to be of the order of 120% over five years, i.e. from 10,600 million ton miles in 1960-61 to 23,350 million ton miles in 1965-66. At the end of 1968, a tremendous variation was found in vehicular traffic in both sectors, i.e. freight and passenger transport. The passenger traffic increased from 98,000 million passenger kilometers in 1968-69 to ~140,000 million passenger km in 1973-74. In order to cater for the estimated increase in traffic, the number of trucks on the roads increased from ~300,000 in 1968-69 to ~470,000 at the end of 1973-74. The number of buses increased from 85,000 to 115,000 during the same period. The production of commercial vehicles increased from 35,000 in 1968-69 to 85,000 in the last year of the 4th YEP. This statistics shows that there was a continuous growth in the number of vehicle and their demand in India historically.

Today, total number of vehicles has crossed 120 million in India. Since the beginning, it was very difficult to handle such large number of vehicles on the roads and they have always created traffic congestion and large number of road accidents in India. Figure 3.6 shows the number of accidents
per lakh population increased from 21.2 in 1970 to 22.8 in 1980, followed by a sharp increase to 33.8 in 1990. Between 2000 and 2005, it fluctuated in the range of 38.6 to 40.1, moving above 42.0 during 2007 and 2008, a slight dip to 41.9 in 2009, again rose to 42.5 in 2010 and declining to 41.1 in 2011 and further declining to 39.9 in 2012 and 38.9 in 2013 respectively which is slightly risen to 40.0 in 2015.

Figure 3.7 shows the trend in the number of accidents per lakh kilometers of the road length shows that the number of accidents have increased over the last few decades, from 960 in 1970 to 1,027 in 1980, peaked to 1,425 in 1990, but declined thereafter, fluctuating within a band of 1,202 to 1,177 per ten thousand kilometers of roads during 2001 to 2008. Then dipped slightly to 1,088 during 2009 and again rose to 1,090 during 2010 and declined to 1,061 and 1,008 during 2011 and 2012 respectively [1].

In more than 90% of road accidents, human error is an important element and often is the

Figure 3.8 shows the causes of road accidents in India [1]:

- Fault of Drivers: 77.1%
- Fault of Cyclists: 0.7%
- Fault of Pedestrian: 1.5%
- Defect in Condition of Motor Vehicle: 2.3%
- Defect in Road Condition: 1.5%
- Weather Condition: 1.2%
- Other Causes: 15.7%
only cause (Figure 3.8). Most common causes of road accidents are over-speeding, driving under influence of alcohol or drugs, driver fatigue, unsafe headways, jumping the red light and unsafe overtaking maneuvers. On top of this, consequences of accidents are aggravated by the fact that many drivers’ co-passengers do not wear seat belts. Accurate, reliable and timely information on traffic queues and other dangerous situations (safety related traffic messages and alerts on incidents, accidents, weather conditions) should be made available by the authorities to the drivers.

Improvement in traffic safety is a very critical issue for road transport sector. According to Ministry of Safety and Highways, road accidents were 9th leading cause of deaths in the country in 2004 and are expected to be 5th leading cause of deaths by 2030 worldwide. This requires serious thoughts and introspection for development of effective traffic planning and safety systems. Fig 3.9 - Shows the Number of Accidents, Persons Killed and Injured in India as per Road Classification in 2013.

Accidents can also be reduced by improving the information available to the road user about the existing speed limits and warning them immediately and swiftly, when these limits are exceeded. Improved navigation information and better route guidance at complex intersections and in unfamiliar places reduces driver stress and contribute to safer driving conditions. There should be awareness that commercial vehicle drivers (which are often slower than traffic) must allow other drivers in passenger vehicles to pass, in order to avoid risky overtaking maneuvers. Better information for the truck drivers on existing traffic constraints also leads to lower collisions and accidents involving trucks. Information to the driver should always be given in a safe way, avoiding any information overload or misuse of information systems. In this respect, a safe human-machine interaction is of great importance. In order to make Indian roads safer, it is important to have a comprehensive plan to achieve the objectives.

It is required to develop an efficient and integrated traffic management system to control and regulate such large number of vehicles operating on Indian roads. Reduction in traffic congestion and optimum use of the existing capacity is a major challenge for the road transport sector's relevance. Estimates suggest that “road congestion costs, including commuting and leisure traffic as well as business and freight traffic” affect Indian economy significantly (~1% of GDP). Several effective plans have already been developed, however, for safe and efficient transportation system, it is essential to have a master traffic plan, which must be capable of controlling vehicular movement with higher levels of safety. The stakeholders including public authorities responsible for provision and maintenance of road infrastructure, vehicle manufacturers, individual drivers and end users of transport must be involved in planning these safety measures.

3.5 GAPS IN SAFETY SCENARIO

Road safety measures have to be taken on priority basis to arrest and reverse the rising road fatalities in India. Driver training which would ensure safe driving, should be encouraged. Road traffic signs and signals need to be periodically checked. Road dividers, barriers should be used to prevent crossover of traffic. Speed limits should be strictly enforced. Driver safety awareness campaigns for seat belts and helmets need to be expedited. Safety devices such as...
ABS, airbags, ESC need to be incorporated even for low end vehicles to make the vehicles safer. Traffic management with collision avoidance and driver warning systems are required to reduce fatalities. Functional accident investigation centers and trauma facilities are required along the highways. The role of ITS particularly in communicating information to all relevant stakeholders (hospitals, police etc.) in case of accidents is very important. All vehicles should be checked for fitness and RTO officials should be trained properly to do a sincere job.

### 3.6 ACTIVE AND PASSIVE SAFETY TECHNOLOGIES FOR ROAD TRANSPORT SECTOR

There are numerous active safety technologies, which can also be adapted in vehicles to improve the safety in transportation sector and vehicles (Table 3.1).

#### TABLE 3.1 ACTIVE SAFETY TECHNOLOGIES

<table>
<thead>
<tr>
<th>Name of Technology</th>
<th>Description</th>
<th>Remarks</th>
<th>Investment Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adaptive Front Lighting</td>
<td>The adaptive front lighting system (AFS) helps to improve visibility during night time driving</td>
<td>Technology used for all vehicles</td>
<td>Technology to be developed in India</td>
</tr>
<tr>
<td>Collision Avoidance</td>
<td>Collision avoidance system uses radar and sometimes laser and camera sensors to prevent an imminent crash</td>
<td>Technology introduced for Cars and SUVs</td>
<td>Investment required for Technology Development in India</td>
</tr>
<tr>
<td>Anti-Lock Braking System</td>
<td>Anti-lock braking system (ABS) allows the wheels on a motor vehicle to maintain tractive contact with the road surface and avoiding uncontrolled skidding</td>
<td>Used for some luxury cars and being introduced for small cars, SUVs</td>
<td>Technology to be developed in India</td>
</tr>
<tr>
<td>Roll Over Protection</td>
<td>Roll over Protection refers to operator compartment frames intended to protect operators from injuries caused by vehicle rollovers</td>
<td>Used for LCV and HCV vehicles</td>
<td>Investment required for Technology Development in India</td>
</tr>
<tr>
<td>Electronic Stability Control</td>
<td>Electronic Stability Control (ESC) is a computerized technology that improves the safety of a vehicle’s stability by detecting and reducing loss of traction</td>
<td>Used for LCV and HCV vehicles</td>
<td>Technology to be imported</td>
</tr>
<tr>
<td>Air Bags</td>
<td>Airbag is an occupant restraint system consisting of a flexible fabric envelope or cushion designed to inflate rapidly during an automobile collision</td>
<td>Used for some passenger cars and SUVs</td>
<td>Technology to be imported</td>
</tr>
<tr>
<td>Tyre Pressure Monitoring</td>
<td>It is electronic system designed to monitor the air pressure inside the pneumatic tires on various types of vehicles</td>
<td>Used for all vehicles</td>
<td>Investment required for Technology development in India</td>
</tr>
<tr>
<td>Driver Assist</td>
<td>Help the driver in navigation or parking</td>
<td>Used for Passenger Cars</td>
<td>Technology to be imported</td>
</tr>
</tbody>
</table>
Following passive safety techniques can be provided for roads to reduce the accidents and improve safety in India (Table 3.2).

### Table 3.2 Passive Safety Technologies

<table>
<thead>
<tr>
<th>Name of Technology</th>
<th>Description</th>
<th>Remarks</th>
<th>Investment required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road markings and dividers</td>
<td>To indicate proper alignment of roads</td>
<td>Technology used for all vehicles</td>
<td>Investment required for provision and maintenance</td>
</tr>
<tr>
<td>Adequate run off area and shoulders on highways</td>
<td>For safety of broken down vehicles</td>
<td>Technology used for all vehicles</td>
<td>Investment required for provision and maintenance</td>
</tr>
<tr>
<td>Use of guard rails or Jersey barriers</td>
<td>To prevent vehicles going off roads</td>
<td>Technology used for all vehicles</td>
<td>Investment required for provision and maintenance</td>
</tr>
<tr>
<td>Material handling equipment for Keeping vicinity of road side free from debris and other obstructions</td>
<td>To prevent vehicle accidents</td>
<td>Technology used for all vehicles</td>
<td>Investment required for provision and maintenance</td>
</tr>
<tr>
<td>Collapsible lighting columns and signs, mounted on shear bolts or made of yielding material</td>
<td>Designed for impact of vehicles</td>
<td>Technology used for all vehicles</td>
<td>Investment required for provision and maintenance</td>
</tr>
<tr>
<td>Safety barriers to contain vehicles within lanes to prevent head on collision</td>
<td>Designed for impact of vehicles</td>
<td>Technology used for all vehicles</td>
<td>Investment required for provision and maintenance</td>
</tr>
<tr>
<td>Transitional Roads</td>
<td>Transitional roads connecting higher-speed roads with lower-speed roads to encourage drivers to slow down in good time</td>
<td>Technology used for all vehicles</td>
<td>Investment required for provision and maintenance</td>
</tr>
<tr>
<td>Rumble strips, speed bumps, visual warnings in the pavement and roundabouts</td>
<td>These assorted technologies can be used to improve safety</td>
<td>Technology used for all vehicles</td>
<td>Investment required for provision and maintenance</td>
</tr>
</tbody>
</table>

3.7 SAFETY ROADMAP FOR INDIA

Road safety has been a priority for a number of years for the policy makers in India. As part of the ‘Road Safety Action Plan 2015-2017’ a target was set to reduce large number of fatalities on Indian roads by 50%. The announcement was accompanied by concerted action on the part of all stake-holders. The following research agenda can be undertaken in short-term, medium term and long term research to improve road safety in India.

3.8 SECURITY TRENDS IN GLOBAL ROAD TRANSPORT

As the United Nations Economic Commission on Europe (UNECE) has noted, transport systems are vulnerable to being used for or being the target of terrorism because they have
TABLE 3.3 RESEARCH AGENDA FOR SAFETY ROADMAP

- **Short Term (1-5 Years)**
  - Evaluating indoor air quality for the cabin by using appropriate gas sensors and appropriate air changes in the cabin with the help of air-conditioning system.
  - Advanced Electronic control system which also includes anti-lock braking system and steering systems to avoid skidding and slipping on slippery roads.
  - Use of vehicle speed governors on public transport vehicles so that accidents due to over-speeding can be avoided.
  - Sensors for wind shield visibility [Visual aids for better night and rain vision]
  - Stricter and uniform driving license examination
  - Compulsory air bags for all passengers
  - Development of efficient parking spaces throughout the country
  - Training of drivers for safety: National unified database for issuing driving licenses
  - Commercial Vehicle Services: Vehicle stability, vehicle diagnostics, driver condition monitoring, automated transactions, safety recorder
  - Low cost Air bags development
    - Within vehicle communications system
    - Driver assistance
      - Active steering for collision avoidance and lane departure
    - Automation of stop-and-go traffic situations
    - Some advanced tools can be provided which may indicate following warnings to avoid collision:
      - Rear end collision warning
      - Intersection collision warning
      - Vehicle to infrastructure

- **Medium Term (5-10 Years)**
  - Safety Impacting: [potential to distract or aid the driver] for navigation and routing, real-time traffic information, and driver comfort and convenience features
  - Pot hole free and well maintained roads
  - Transit: obstacle and pedestrian detection, precision docking, passenger monitoring, passenger information
  - Low cost Air bags development
    - Vehicle to vehicle collision avoidance and platooning
    - Driver assistance
      - Active braking
    - Some advanced tools can be provided which may indicate following warnings to avoid collision:
      - Lane change/ Lane merge collision warning
      - Railroad crossing collision warning
      - Vision enhancement
      - Location specific warnings

- **Long Term (10-20 Years)**
  - Situational aware vehicles
  - Supporting Services: low friction warning, longitudinal control, lateral control

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not been designed to cope with security threats. Traditionally, the focus has been on smooth, fast and reliable flows, while achieving certain safety rather than security standards. In addition, road transport infrastructure is easily accessible and often lacks surveillance (such as major roads, bridges and tunnels), and goods vehicles are readily available and can be used as either a means of conveying weapons or as weapons themselves. Also, complexity presents major problems. Supply chains involving international road freight consist of thousands of companies and The UNECE’s Inland Transport Committee has reviewed issues that could benefit from further security considerations. In the field of land-based freight transport, these include Vehicle regulations (concerning vehicle alarm and immobilization systems and agreements on provisions for immobilizing vehicles after unauthorized use and the installation of positioning systems in vehicles to identify their location). Dangerous goods and special cargos (the need for security recommendations for transport of dangerous goods and to consider updating training requirements for drivers and other personnel involved). There is no international body for land transport security (for goods and passengers), that is equivalent to bodies in maritime and air security. The existence of such organizations would make it easier to introduce international standards and rules (UNECE, 2008).

Although it is important for OEMs to continuously monitor vehicle theft rates across all markets, it is even more important to understand why theft rates are changing and what impact this could have on automotive security strategies. In future, all vehicles will be fitted with electronic immobilizers and no one will offer alarms. Instead, some OEMs are prioritizing features that provide visible (although less effective) security to consumers compared to immobilizers. Remote operation and mobile based tracking systems will improve the vehicular security.
3.9 VEHICLE SECURITY TRENDS IN INDIA

Every six minutes, a vehicle is stolen in India. More than 65% of the vehicles have a normal vehicle alarm system. Unattended vehicles, remote parking lots and unreliable valet place a huge burden on the vehicle owner, with no easy solution in sight. There is also rampant misuse of vehicles (especially cars and vans) by drivers, who take advantage of the owner’s ignorance and absence. Vehicle security systems have become important to challenge security related concerns arising from theft, terrorism, riots, arson and other unforeseen situations. The main types of vehicle security systems used in India are audible and inaudible. Audible security systems work by alerting the general public that someone without authority is trying to get into the vehicle. Whereas in inaudible security systems, vehicle owner gets alert about the intervention without the intruder coming to know about it. Overall security of vehicles and roads is inadequate in current scenario in India.

3.10 GAPS IN SECURITY SCENARIO

Security of vehicles is an important area due to countless incidents of car thefts. Security of vehicles should be enhanced with anti-theft devices which are alarm based or operate remotely. Remote disabling of the ignition after alarms, finger print identification for starting the vehicle are some important technology solutions. Round the clock surveillance should be introduced on roads to prevent any untoward incidents. Protection from terrorist strike is important, therefore, remote surveillance technologies are the need of the hour. CCTVs in public areas, protection of bridges and tunnels are some measures required in India.

3.11 VEHICLE COMMUNICATION AND TELEMETRICS

Vehicular security is an important area and is receiving attention in the light of thefts and terror strikes in India. Several technologies are available. New GSM based devices are also popular because they send ‘vehicle theft’ alerts in case of intrusion (opening of door), vehicle tracking by SMS and keyless entry. Vehicle data recorders and telematics are not a future possibility, but are currently available technologies, awaiting large scale implementation. As the costs decrease, many industries, including insurance companies are taking a second look at utilizing these devices to improve services and to develop innovative solutions for improving vehicular safety. There are four types of “devices” i.e. trip logging devices, passive GPS tracking devices, Crash data recording devices and telematics devices. Privacy concerns tend to dominate any discussion of vehicle data recording and insurance. One way to address the privacy concern is to allow the owner of the data to choose who has access to the data in return for the benefits. Owners of commercial fleets do not have the same privacy concerns as individual drivers. They want to know exactly where their vehicles are located, how fast they are being driven and so on. A comprehensive vehicle security system will encompass the following technologies (Table 3.5).


4.0 ENERGY, ENVIRONMENT, EMISSIONS AND NOISE ISSUES

4.1 INTRODUCTION

Energy is a basic requirement for economic development. Growing energy consumption in India has also resulted in increasingly dependent on fossil fuels such as coal, oil and gas. India urgently needs to develop a sustainable path of energy. Biofuels seems to have the potential to contribute significantly to India’s energy security. However, a clear choice needs to be made on priorities. The fuel costs are rising and are dependent on crude oil price. Further, availability of uniform quality gasoline and diesel throughout the country is a major issue. Distribution infrastructure of fuels needs to be strengthened. Sustained availability of fossil fuels has to be ensured. Fuel quality is also affected by issues such as adulteration. Development of high performance additives is essential. Availability of gaseous fuels like CNG needs to be improved. Infrastructure for dispensing alternative fuels like CNG and LPG and charging electric and hybrid vehicles needs to be established. New synthetic fuels such as DME, GTL need to be encouraged.

Fossil fuels supply more than 80% energy for global consumption and more than 95% energy for transport sector globally. While global fossil fuel reserves are diminishing, worldwide energy demand is constantly increasing due to the evolution of energy intensive life styles. Experts estimate that the global demand for energy could rise by more than 50% between 2009 and 2030 and the oil production will reach a peak around 2020-30. Burning fossil fuels generates CO₂, a greenhouse gas leading to global warming. It is therefore, necessary to find cleaner fuels that do not depend on fossil resources.

Vehicular pollution cannot be avoided because the pollutants are emitted at the ground level, close to human breathing level. Severity of vehicular pollution is reflected in increased human mortality and morbidity and increased symptoms like cough, headache, nausea, irritation of eyes, various bronchial problems and visibility in affected population. Vehicular pollution affects human health adversely due to presence of CO, unburned HC, NOx, soot, suspended particulate matter (SPM) and aldehydes, among others in the engine exhaust. Apart from these harmful pollutants, CO₂ leads to various long-term global problems including greenhouse effect. Almost all countries are working on the methods of CO₂ emission reduction from engine tailpipe to combat with this menace. Different air pollutants from the vehicles have effects at all levels – local (e.g., smoke affecting visibility, ambient air; noise etc.), regional (such as smog, acidification) and global (i.e., global warming). Automobiles besides being the prominent source of air pollutants also account for a number of external effects, such as congestion, noise, accidents, road wear and tear; etc.

4.2 GLOBAL ROAD TRANSPORT

CURRENT ENERGY TRENDS: Global transport sector consumed about 2,200 million tons of oil equivalent (mtoe) in 2010, constituting about 19% of global energy supplies. Figure 4.1 shows that a significant amount came from oil, while the rest of transport energy was from natural gas, biofuels, and electricity.

As the figure 4.1 shows, road transport accounts for the bulk of the transportation energy consumption. The light-duty vehicles (LDVs), including light-duty trucks, light commercial vehicles, and mini-buses accounted for about 52%, while trucks, including medium and heavy-duty, accounted for about 17%. Remaining share of road transport was occupied by buses (4%) and two/three wheelers (3%). Road transport has always dominated the transport sector. For non-OECD countries, the fastest-growing energy use was by road transport (LCVs, trucks, buses, and two-three wheelers).
4.3 GLOBAL ROAD TRANSPORT: FUTURE ENERGY TRENDS:
IEA scenarios have predicted the world transport energy use to increase by more than 50% by 2030 and more than double by 2050. The fastest growth is expected to come from air travel, road freight and light-duty vehicles, with road transport accounting for bulk of growth. From 1971 to 2013, global transport energy usage increased steadily at a rate of 2% and 2.5% per year, closely paralleling growth in economic activity globally. As per the world energy council, the total fuel demand in all transport modes will increase by 30% in 2035 above the 2010 levels. The growth in fuel demand will be driven mainly by trucks and buses. Transport sector fuel mix will still depend heavily on gasoline, diesel, and fuel oil till 2035 as they will still constitute the bulk of transport market fuels. Demand for diesel is expected to increase by 10% and for gasoline, it is expected to decrease by 16%. Biofuels will also help satisfy the demand for transport fuel as their use is expected to increase almost four fold by 2035. Other fuels including electricity, hydrogen, and natural gas will increase six to seven fold by 2035.

4.4 FUEL ECONOMY IMPROVEMENT AND CO₂ EMISSION REDUCTION OPTIONS
Fuel economy for automobiles can be characterized as the distance travelled per unit of fuel used; similarly another related measure is the amount of carbon dioxide (CO₂) produced as a result of the combustion process, typically measured in grams of CO₂ per kilometer (CO₂ g/km). The fuel economy of a vehicle is affected by the weight, shape, and size of the vehicle. Due to rapid population growth, India has become one of the prominent emitters of pollutants from the road transport sector globally. Strong motorization of the country has led to increasing concerns about local and global air pollution and their impact on climate change and on demand for petroleum.

Indeed, by 2000, India was amongst the top ten countries emitting highest exhaust pollutants from the road transport sector (Borken et al., 2007). India’s transport fuel consumption has almost doubled every decade since 1980. CO₂ emissions in road transport have increased from 57-70 Tg in 1990 to 134-220 Tg in 2005. A research study carried out by Lee Schipper showed that CO₂ levels will cross the critical limits by 2030 as shown in Figure 4.2. This research showed four possibilities under three different categories: Business as Usual (BAU), Energy efficiency (EF), Two Wheeler World (TWW) and Sustainable Urban Transport (SUT). SUT reflects policies aimed at truly lifting urban infrastructure constraints by demand management and installing modern mass transit systems as the backbone of clean mobility. TWW is the second scenario, which reflects a mobility scenario based on small, clean vehicles. EF is the third scenario reflecting a policy focus aimed at oil saving and thus using renewable fuels in all transport modes. BAU projections are based on an assumption of GDP and population growth. Here, the data shows that in next few years, cars will be the major source of CO₂ emissions and it will quickly double from current levels.

There are numerous approaches, which can be taken up to reduce CO₂ emission levels from the road transport sector in India. These approaches include use of low carbon fuels,
hydrogen, fuels from bio-origin, use of advanced and more efficient engine technologies such as gasoline direct injection (GDI) and homogeneous charge compression ignition (HCCI), engine efficiency improvement, improved traffic management, improved road conditions and road network, and active CO$_2$ sequestration by planting trees around heavy traffic corridors.

Possible interventions for CO$_2$ reduction in India can be classified based on three different scenarios (Downsizing, hybridization and electrification) as shown in figure 4.3.

Downsizing: Scenario 1 assumed that new registrations of vehicles are shifted from larger to smaller cars. This is a tendency which is obvious, with all mainstream manufacturers extending the range of smaller cars offered (i.e. below 1.4 l engine capacity). Downsizing reduces emissions as a result of less energy required to operate small and lighter vehicles.

Hybridization: Scenario 2 introduced a large number of gasoline hybrid vehicles. Hybrid vehicles benefit from the combined operation of an internal combustion engine and an electric motor which assists the engine over accelerations and high load conditions. As a result, a smaller engine than in a conventional vehicle may be used which operates under less transient conditions. This results to higher overall efficiency.

Electrification: Scenario 3 considered the introduction of electric vehicles, i.e. vehicles where power to the wheels is delivered by an electric motor and which can be charged directly from the power grid. An electric vehicle with range extender was considered as the best example, i.e. a vehicle where an internal combustion engine charges the batteries when depleted. This differs from hybrid because power to the wheels is provided only through the electric motor. However, such an electric vehicle is not compromised by a small range. Therefore, it appears as the best of both worlds.
A detailed research agenda for CO₂ reduction is discussed based on three different time frames as short term, medium term and long term duration. Table 4.1

**TABLE 4.1 VEHICLE WEIGHT REDUCTION, MATERIAL AND DESIGN ASPECTS**

**SHORT TERM (1-5 YEARS)**
- Reduced use of steel BIW in vehicle construction
- Increased use of aluminum, lighter alloys and plastics
- Weight reduction of seats, glazing and interior components
- Reduction in tyre rolling losses
- Drag reduction through fit and finish and styling details
- Introduction of structural composites

**MEDIUM TERM (5-10 YEARS)**
- Drag reduction from form changes
- Active aerodynamics for losses reduction
- Small light weight vehicles for urban usage
- Larger low drag vehicles for trucking

**LONG TERM (10-15 YEARS)**
- Change in vehicle sage/ownership patterns allows specialization of vehicle design
Fuel economy of a vehicle can be improved by various strategies as given in the Table 4.2 below.

**TABLE 4.2  FUEL ECONOMY IMPROVEMENT TECHNOLOGY**

<table>
<thead>
<tr>
<th>Name of Technology</th>
<th>Description</th>
<th>Remarks</th>
<th>Investment Required for R&amp;D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine Downsizing</td>
<td>Reducing size of the engine for achieving same power</td>
<td>Technology used for SUVs and LCVs</td>
<td>Nil</td>
</tr>
<tr>
<td>Hybridization</td>
<td>Incorporation of electric battery and motor to supplement the IC Engine</td>
<td>Used for some luxury cars and being introduced for small cars, SUVs</td>
<td>Yes. Investment required to produce low cost electronics and batteries</td>
</tr>
<tr>
<td>Use of Continuously Variable Transmission</td>
<td>Use of continuously variable transmission automatic gearbox instead of epicyclical gearboxes with torque converter couplings</td>
<td>Used for some passenger cars</td>
<td>Yes. Investment required to develop indigenous CVT</td>
</tr>
<tr>
<td>Vehicle Light Weighting</td>
<td>Reducing vehicle weight by using lighter materials such as aluminum, fiberglass, plastic, high-strength steel and carbon fiber</td>
<td>Used for LCV and HCV vehicles</td>
<td>Yes. Investment required to develop indigenous composites, high strength alloys, and nano materials</td>
</tr>
<tr>
<td>Vehicle Aerodynamics</td>
<td>Designing the shape of the vehicle and the internal cooling system in order to reduce aerodynamic drag</td>
<td>Used for some passenger cars and SUVs</td>
<td>Yes. Investment required to develop wind tunnel facilities in India. At present, there is none</td>
</tr>
<tr>
<td>Tyre Pressure monitoring</td>
<td>Increasing pressure of tyres to lower tyre deformation under weight</td>
<td>Used for some vehicles</td>
<td>Nil</td>
</tr>
<tr>
<td>Regenerative Braking</td>
<td>Recapturing wasted energy while braking</td>
<td>Used for hybrid Passenger Cars</td>
<td>Investment required to develop hybrid vehicles with all technologies.</td>
</tr>
<tr>
<td>Synthetic Lubricants</td>
<td>Friction reduction by using better quality synthetic lubricants</td>
<td>Used for all vehicles</td>
<td>Investment required for development</td>
</tr>
<tr>
<td>Locking Torque converters</td>
<td>To reduce slip and power losses in the converter</td>
<td>Used for passenger cars</td>
<td></td>
</tr>
<tr>
<td>Biofuels</td>
<td>Reduction in CO₂ emissions</td>
<td>Used for SUVs and HCVs</td>
<td>Investment required for establishing infrastructure for harvesting, production and dispensing</td>
</tr>
</tbody>
</table>
4.5 ROADMAP FOR FUELS IN INDIAN TRANSPORT SECTOR

At present, petrol and diesel are the main automotive fuels used in India. Personal transport vehicles like two wheelers and cars are mainly operated on petrol and the public/ commercial transport like buses, trucks and other light and heavy-duty vehicles mainly run on diesel. Bureau of Indian Standards (BIS) notifies standards for auto-fuel quality including petrol, diesel, CNG, LPG etc. There are a total of 15 parameters in petrol specifications out of which 4 are environment related parameters. Similarly, there are a total of 16 parameters in diesel specifications, out of which 4 are environment related parameters. Current BIS 2000 specifications for petrol (IS 2796) and diesel (IS 1460) respectively are applicable in the country. The new auto fuel policy is being discussed and will outline the roadmap for quality of fuel supplied throughout the country in light of the forthcoming stringent emission norms. Refer Figure 4.4 for report / findings of SIAM on the fuel quality variation in India.

**CHALLENGE TO VEHICLE MANUFACTURERS:**
- DIFFERENT FUEL QUALITY IN DIFFERENT PARTS

<table>
<thead>
<tr>
<th>FUEL QUALITY</th>
<th>MEGA CITIES</th>
<th>MAJOR CITIES</th>
<th>REST OF INDIA</th>
</tr>
</thead>
<tbody>
<tr>
<td>EURO II</td>
<td>April 2001</td>
<td>April 2003</td>
<td>April 2005</td>
</tr>
<tr>
<td>EURO III</td>
<td>April 2005</td>
<td></td>
<td>April 2010</td>
</tr>
<tr>
<td>EURO IV</td>
<td>April 2010</td>
<td></td>
<td>Not Decided</td>
</tr>
</tbody>
</table>

- INDIA EMISSION REGULATIONS = EU REGULATION
- REQUIRED FUEL = MATCHING EURO FUEL AT LEAST ONE YEAR BEFORE DATE OF IMPLEMENTATION OF THE EMISSION NORMS

**FIG 4.4**
FUEL QUALITY IN INDIA

- MEGA CITIES
- MAJOR CITIES
As of now, Euro IV emission levels are applicable in 13 major cities of India and rest of the country has Euro III norms. Introduction of new BS-V and BS-VI norms in April 2017 depends on improvement in vehicle engine technology and availability of cleaner fuel by petroleum companies. The petroleum companies have to invest Rs 40,000 core to meet Euro V norms and it is estimated that similar amount will be required to meet Euro VI norms. The advent of lower sulphur diesel fuel is a key development in the worldwide effort to reduce air pollution and public health impacts associated with diesel vehicle emissions.

4.5.1 GASEOUS FUELS CNG, LPG AND LNG
These gaseous fuels contain more hydrogen and less carbon, therefore, the emission of greenhouse gases and fine particulates is lower from these fuels. Nylon and Lawson (2000) found that diesel combustion emitted 84 mg/km of fine PM as compared to only 11 mg/km in CNG. CNG/LPG/LNG does not contain poly-aromatic hydrocarbons (PAHs), airborne toxins and SO$_2$, and CNG/LPG/LNG vehicles have quieter engine operation, less vibrations and odour than conventional diesel engines. However, higher vehicle cost, shorter driving range, heavier fuel tank, expensive distribution and storage network and potential performance and operational problems compared to liquid fuels are some of the drawbacks of using CNG/LPG/LNG vehicles.

4.5.2 METHANOL AND DI METHYL ETHER (DME)
Methanol and DME have emerged as potential long-term substitutes of oil and natural gas. Technologies for production of liquid phase
methanol & DME are available and can be improved and implemented by existing refineries. As India generates significant quantity of solid wastes and having thousands of landfills sites, the use of land fill gases (LF)/MSW to produce methanol may be explored. Technology options for gasification of high ash Indian coal (typically 34-40%) can be pursued. Studies are required to assess the techno-economic feasibility for production of methanol/ DME through this route. Use of direct methanol fuel cells (DMFC) in transport applications is at R & D stage. Research efforts are underway for development of a downsized /turbocharged SI dedicated methanol engine with same torque and efficiency as of diesel. However, M 85 or 100% methanol application would require augmentation of availability of Methanol.

4.5.3 BIOFUELS

Biofuel production from renewable sources is widely considered to be one of the most sustainable alternatives to petroleum fuels and a viable means for environmental and economic sustainability. Refer Figure 4.5 for the biofuel generation technologies. Biofuels are also an alternative for powering vehicles, replacing traditional petroleum based fuels. The complete landscape of different generations of biofuels is shown in the figure 4.5.

Development of 1st generation biofuels: First-generation biofuels are extracted from agricultural products such as beetroots, rape-seed, etc. However they compete with food production. Second-generation biofuels are produced using the non-edible part of plants (straw, wood, plant waste). Unlike first-generation biofuels, they do not compete with the use of raw materials as food.They can be used directly in conventional vehicles and will considerably reduce CO₂ emissions.

Development of 2nd generation biofuels: Biomass is the oldest source of energy since ancient time and currently accounts for roughly 10% of total primary energy consumption globally. While traditional biomass in the form of fuel wood remains the main source of bioenergy, liquid biofuel production has shown rapid growth during last decade. Second-generation biofuels, produced from the non-edible part of plants are used to power vehicles, thereby limiting their CO₂ emissions. With recent developments in automotive technology, it is required to produce better quality, low cost biofuels. For this, research on advanced technologies for conversion of raw materials to high quality biofuels is required.

Development of 3rd generation biofuels: First and second generation biofuels like ethanol and biodiesel have a number of inherent limitations which make them less than ideal as a long-term replacement for petroleum fuels. The primary feedstock for first generation ethanol (corn and sugarcane based) and biodiesel (rapeseed, soybeans, and palm based) are crop based, which competes with food crops for scarce land resources, fresh water, and fertilizers. These fuels cannot be used in unmodified engines beyond minor blends. First and second generation biofuels account for more than 99% of current global biofuel production, therefore there is a need to develop third generation fuels in order to avoid this “Food vs. Fuels” dichotomy. Microalgae are currently being promoted as an ideal third generation biofuel feedstock because of their rapid growth rate, CO₂ fixation ability and high production capacity of lipids. Algae also does not compete with food crops for resources, and can be easily produced on non-arable land. Microalgae have broad bio-energy potential as they can be used to produce liquid transportation fuels, such as biodiesel and bio-ethanol.

During recent years, the production of many first-generation biofuels has faced severe criticism regarding its sustainability. On the one hand, rise in agricultural commodity prices have spurred discussions as to what extent first-generation biofuels can be produced without adversely affecting the food production. Despite the fact that some of the currently produced biofuels are performing well in terms of economic and environmental sustainability, ongoing debates shifts focus onto second and third generation biofuels, which are based on non-edible biomass and promise to avoid the sustainability concerns related to current biofuel production. Therefore in long-term, it will be necessary to develop industrial scale biofuel production capability for second and third generation biofuels. The alternate fuel landscape in India is shown in table 4.3.
<table>
<thead>
<tr>
<th>Fuel</th>
<th>Description</th>
<th>Remarks</th>
<th>Investment Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>CNG</td>
<td>Compressed natural gas contains methane which is an environmentally friendly fuel lowering CO and HC emissions</td>
<td>Technology used for 3 Wheelers, Passenger cars, LCVs and HCVs</td>
<td>Investment required for more dispensing stations and pipelines</td>
</tr>
<tr>
<td>LPG</td>
<td>Liquefied petroleum gas contains propane and butane which lower CO and HC emissions</td>
<td>Technology used for 3 Wheelers, Passenger cars</td>
<td>Investment required for more dispensing stations and pipelines</td>
</tr>
<tr>
<td>HCNG</td>
<td>Blend of hydrogen and natural gas used as a trial fuel and not commercially introduced</td>
<td>Technology proposed for HCVs</td>
<td>Investment required for blending and dispensing stations</td>
</tr>
<tr>
<td>LNG</td>
<td>Liquefied natural gas improves carrying capacity of the vehicle and is not yet commercially introduced</td>
<td>Technology proposed for HCVs</td>
<td>Investment required for dispensing stations, vaporizers and pipelines</td>
</tr>
<tr>
<td>Biogas</td>
<td>Biogas also contains methane which is an environmentally friendly fuel lowering CO and HC emissions</td>
<td>Proposed for LCV and HCV vehicles</td>
<td>Investment required for fuel upgradation, and dispensing stations</td>
</tr>
<tr>
<td>Ethanol</td>
<td>Alcohol which is blended with gasoline as a 5% blend and is proposed to be increased to 10%</td>
<td>Used for some passenger cars and SUVs</td>
<td>Investment required for dispensing stations and blending</td>
</tr>
<tr>
<td>Biodiesel</td>
<td>Esterified Vegetable oil which can be used as a blend with diesel</td>
<td>Used for SUVs and HCVs</td>
<td>Investment required for production, dispensing stations and blending</td>
</tr>
<tr>
<td>Synthetic Fuels</td>
<td>Artificial fuels derived from natural fuels using Fischer Tropsch process</td>
<td>Technology proposed for passenger cars</td>
<td>Technology needs to be imported</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>Freedom fuel which is currently under trial.</td>
<td>Technology proposed for Passenger cars, and HCVs</td>
<td>Investment required for production and dispensing stations</td>
</tr>
<tr>
<td>Methanol and DME</td>
<td>Methanol &amp; DME are potential long-term substitutes of oil and natural gas.</td>
<td>Methanol &amp; DME can be utilised either in pure form or blended with conventional fuels in SI and CI engines. It also acts as energy carrier &amp; as feedstock for natural gas/methane, biodiesel, etc.</td>
<td>Investment required for production, blending and dispensing stations.</td>
</tr>
</tbody>
</table>
4.6 FUEL EFFICIENCY AND FUEL QUALITY IMPROVEMENT
Fuel efficiency norms will be applicable in India shortly. Meanwhile, Society of India Automobile Manufacturers (SIAM) introduced a voluntary scheme of fuel efficiency marking on vehicles. The task of framing the official fuel efficiency standard was entrusted to BEE (Bureau of Energy Efficiency). The rating of vehicles is done on the basis of five star rating. The labels include an informative component (the fuel consumption of the model in liters/100 km) and a comparative component (the star rating of the model on a five-star scale). The entire gamut of vehicles will be rated as per the five star rating scheme. The compliance for manufacturers is being specified in terms of Corporate Average Fuel Consumption (CAFC). India has a fleet average CO₂ of 141 g/km at present. India may follow the EU which started with 140 g/km of fleet average and is at 120 g/km in 2012 and aims 95 g/km in 2020.

Fuel quality has significant direct and indirect consequences for diesel vehicle emissions. Reducing sulphur in diesel reduces direct emissions of sulfate particles as well as emissions of sulphur dioxide (SO₂), which can convert into particles and acids in the atmosphere. As shown in Figure 4.6, more than half of all diesel fuel globally are supposed to have sulphur levels of 50 ppm or less by 2010. India is expected to move to uniform fuel quality by 2020. Low sulphur diesel with less than 10 ppm sulphur will be required to meet Euro-V and Euro-VI norms. The new auto fuels policy 2035 has been released by the Ministry of Petroleum, Government of India.

Apart from all these areas, a lot could be done to explore new fuels to power the transport sectors and make them more environment-friendly, as mentioned in Table 4.4.

**TABLE 4.4 VEHICLE WEIGHT REDUCTION, MATERIAL AND DESIGN ASPECTS**

<table>
<thead>
<tr>
<th>SHORT TERM (1-5 YEARS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industrialization of 1st general biofuels.</td>
</tr>
<tr>
<td>Proper infrastructure for production and distribution of biofuels. Availability of different feedstocks.</td>
</tr>
<tr>
<td>Increased use of waste products as feedstock: (Biofuels can be made from different resources. Production of biofuels from waste materials such as waste cooking oil and under-utilized non-edible oils.)</td>
</tr>
<tr>
<td>Development of 2nd generation biofuels: (Second-generation biofuels, produced from the non-edible part of plants are used to power vehicles, thereby limiting their CO₂ emissions. With recent developments in automotive technology, it is required to produce better quality, low cost biofuels. For this, research on advanced technologies for conversion of raw materials into high quality biofuels is required.)</td>
</tr>
<tr>
<td>Development of ultra low sulfur fuels for lower emission as well as vehicle life</td>
</tr>
</tbody>
</table>
Implementation of large scale EV recharging infrastructure, including integration to grid demand, fast charge capability

Demonstration of 2nd generation biofuels at industrial scale (process and distribution infrastructure)

Battery’s thermal Management: It is needed to analyze vehicle battery thermal management systems to improve battery performance, life, and safety. By using thermal analysis and laboratory testing results, battery suppliers and automotive manufacturers can improve module and pack designs

Use of off-shore wind energy based hydrogen production

Development of unified fuels such as JP-8

Development of hydrogen generation and distribution infrastructure: Hydrogen can be produced in large scale to sustain whole transport sector using solar energy and nuclear thermal energy.

Large scale, high power, intelligent charging infrastructure for mass penetration of EVs across the length and breadth of the country and on the highways.

Use of nuclear power for hydrogen production (thermal routes)

Development of off-shore gas hydrates for natural gas production

Development of 3rd generation biofuels: (Microalgae are currently being promoted as an ideal third generation biofuel feedstock because of their rapid growth rate, CO₂ fixation ability and high production capacity of lipids. Algae also does not compete with food crops for resources, and can be easily produced on non-arable land. Microalgae have broad bio-energy potential as they can be used to produce liquid transportation and heating fuels, such as biodiesel and bio-ethanol.)

Industrial infrastructure for production of 2nd and 3rd generation biofuels

4.7 GLOBAL ROAD TRANSPORT: CURRENT EMISSIONS TRENDS
Today the transport sector is responsible for 23 - 24% of global CO₂ emission from fossil fuel combustion (with road transport 17-18% of this total). The transport sector has the highest CO₂ emissions growth of all sectors; aviation and road transport are the main contributors of this growth. Net CO₂ reduction costs are achievable. It is important that the efficiency gains are not simply offset by trends toward even larger, heavier, and faster cars. Fossil fuel use is the primary source of CO₂, and methane (CH₄). Nitrous oxide (N₂O) emissions from transportation sector are primarily due to fossil fuels combustion.

4.8 GLOBAL ROAD TRANSPORT: FUTURE EMISSIONS TRENDS
In response to the challenging new fuel-economy standards, higher fuel prices, and tighter emissions controls, transport manufacturers are motivated to find new ways to improve efficiencies and make transport more environment friendly. In long term, the manufacturers can potentially achieve a reduction of about 28%–33% emissions from conventional IC engines, 41%–45% for
hybrids, and about 54%-55% for plug-in LCVs. Evidently, additional range economy can be realized through improvements that include aerodynamic streamlining, improvements in tyre rolling resistance, improved lighting, improved air-conditioning systems, and optimization of the vehicle’s body using composite materials. Improvements in trucks, buses, are expected to improve fuel efficiency in the long run too. The International Energy Agency (IEA) has estimated that fuel consumption and emissions of CO₂ from the world’s cars will roughly double between 2000 and 2050. CO₂ emissions from fossil fuel combustion will increase 45% from 2006 to 2030, with 97% of this increase occurring in non-OECD countries. One-fifth of this increase is the result of global transport-related GHG emissions – 98% of which will occur in developing countries. In order to support global reductions in CO₂ emissions from the transport sector, technical innovation will have to go hand-in-hand with supporting policies – and there is a clear opportunity to reduce CO₂ emissions by 30% by 2020 and 50% by 2035. Improving the efficiency of new cars, from incremental technology improvements and hybridization, at this rate would make possible a 50% improvement in the average fuel economy of all cars on the road worldwide by 2050, likely to be cost effective even at relatively low oil prices. Figure 4.7 shows the global emission trends from road transport sector.

4.9 EMISSION TRENDS IN INDIAN ROAD TRANSPORT SECTOR

India has gone way ahead in implementing emission norms over the last two decades and has been able to close the gap between India and Europe from 15 years to ~5 years. In last one decade, India has moved from BS- I regulations to BS-IV regulations. Further reduction in emission levels in commercial vehicle industry will depend upon the availability of cleaner diesels with low sulphur. European Union still has a lead of approx. 5 years in implementation of emission norms compared to India therefore similar practices need to be adopted in India as well. Since emission levels are shrinking therefore engineering solutions to attain such low levels are becoming more complex and are closely linked with engine and vehicle parameters.

FIG 4.7 GLOBAL ROAD TRANSPORT FUTURE EMISSION TRENDS [8]
Current emission norms in India are given in figure 4.8.

Enforcement of uniform emission norms throughout India will be possible only after 1st April 2017. Currently metro cities have emission norms, which are at a level higher than the rest of the country. On-road vehicle emission control should be affected by strengthening the PUC system. Fuel quality also affects the emissions therefore effective fuel quality measures need to be taken. Enforcement of emission control devices such as TWC, DPF, SCR and DOC on vehicles is required to curb vehicular pollution. Research should be undertaken to develop superior catalysts, which are tolerant to high sulphur Indian fuel. Fuel economy standards need to be introduced along with measures for reducing CO₂ emissions. Efforts for improving fuel economy of fleets should be encouraged. Inspection and maintenance regime should be introduced for all vehicles to ensure good emission performance of all vehicles.

4.10 EMISSION ROADMAP

Emission of vehicles while operating in the field is largely dependent upon the quality of fuel, average speed of operation and the health of the vehicle depending upon the maintenance practices followed by the operator.

The comparison of emission norms for major countries is given in figure 4.9. According to a report issued by NASA Earth Center, current trends suggest emissions will drop slightly around 2020 and then grow quickly as the number of cars on the road increase (figure 4.9). If most countries adopted European standards, there would be a major drop in Nitrogen oxide (NOₓ), black carbon, and sulfur dioxide (SO₂) levels. European standards further reduced fuel sulphur levels for gasoline and diesel to a maximum of 10 ppm in 2009 which significantly affects SO₂ emissions. India is expected to follow the EU roadmap and introduce Euro-V and Euro-VI emissions in the country in near future.
India is currently experiencing rapid motorization growth. Indian government and policy makers are dealing with the fast economic growth riding on inadequate and unsustainable infrastructure, which is developed as a knee-jerk response mostly created as a result of pressure from private automotive manufacturers. Although more than half the passenger trips are being done using public transport in India even today, and a fairly large share of non-motorized transport in rural India, country is well poised for sustainable development in road transport sector. The health costs of traffic-related air pollution are very high which includes premature deaths, hospitalization and loss of productivity. Results show that various engine generated pollutants are continuously increasing. Other major pollutants such as $SO_2$ and CO are also increasing with growth in the number of vehicles as shown in figure 4.10. However, several reports show significant reduction of emission from the road transportation. The most reduction in emissions between 1998 and 2012 occurred as a result of implementation of four sets of vehicular emission standards, removal of lead, reduction of sulphur content, mandatory disposal of older commercial vehicles, and conversion of diesel and petrol run public transport vehicles to compressed natural gas. In addition, changes in the vehicular
technology have also contributed in controlling emissions especially in case of auto-rickshaws and motorized two-wheelers, which changed from two-stroke to four-stroke engine. The rising trend of NOx along with the presence of VOCs indicates increasing tendency to form ground-level ozone and as a result, smog in the region. We predict that the current regime of vehicle technology, fuel standards, and high growth rate of private vehicles, is likely to nullify all the past emission reductions initiatives by the end of 2020’s.

**FIG 4.10 DISTRIBUTION OF POLLUTANTS BASED ON TIME SPAN [11]**

- **(A) PM$_{2.5}$**
- **(B) SO$_2$**
- **(C) NO$_x$**
- **(D) CO**
- **(E) VOC**
- **(F) CO$_2$**
Another interesting result shows that 2-wheelers, cars and heavy duty vehicles are the major source of different harmful pollutants such as oxides of nitrogen, carbon dioxide and sulphur dioxide. The generation of these pollutants is higher in Indian metropolitan cities due to higher mobility. Variation in production of major pollutants such as CO in different regions of India is given in figure 4.11.

Figure 4.12 shows the annual average respirable suspended particulate matter (RSPM) concentration of major cities in India. A fluctuating trends in RSPM levels, indicates increasing trend in Delhi, Mumbai and Kolkata but for Chennai, it shows decreasing trend. The reason for high particulate matter levels is attributed by vehicular traffic, diesel/kerosene generator sets, small-scale industries, biomass incineration, suspension of traffic dust, commercial and domestic use of fuels.

A large number of technologies are currently being employed to reduce the emissions of these harmful vehicular pollutants from the vehicles and a large number of technology interventions are therefore being planned/implemented to meet the objective of controlling these pollutants. These new interventions include development of cheap non-noble metal based catalysts for exhaust gas after treatment, on-board diagnostics for lubricating oils, use of various efficient after-treatment technologies such as three way catalysts, diesel oxidation catalysts, exhaust gas recirculation, selective catalytic reduction, lean NOx traps, particulate traps, plasma traps, fuel borne catalysts etc.

Modern interventions are also required for better understanding of pollutant formation processes inside the engine cylinder and therefore, advanced laser diagnostic techniques and micro-sensors have a huge role to play in control of pollutants from the engine systems. There is also a great need to understand the role of pollutant sources in an automobile other than engine such as tyres and better understand road-tyre interaction, which leads to formation and emission of large number of nano-particles into the atmosphere.

Congestion leads to double whammy on engine emissions. The time cost of a vehicle kilometer rises rapidly with increased congestion. This is because the addition of a vehicle to an already crowded network increases travel time for other passengers as well. Since the average speed reduces to levels that are far below the optimal operating vehicles speed, this leads to increase in emissions per km, thus the two effects are inter-linked. As an example, the congestion costs are nearly US$ 14 billion in terms of excess time required and gasoline consumed to the commuters in California, in addition to substantial environmental damage. Since VOCs and CO are 250% higher in congested conditions than during free flowing traffic. Therefore, air quality degradation is a natural consequence of traffic congestion.

4.1.2 GLOBAL ROAD TRANSPORT: CURRENT NOISE TRENDS

The vehicular noise now constitutes the major problem in traffic noise in the highly industrialized countries. The term tyre/road noise denotes the noise emitted from a rolling tyre as a result of the interaction between the tyre and the road surface. Vehicle noise is composed mainly of tyre/road noise and noise from the powering of the vehicle, what is here called power unit noise. Power unit noise is composed of noise from the engine and all its “accessories”, the exhaust system and the transmission. Both tyre/road and power unit noise have strong relationships with vehicle speed. First, one shall recognize that tyre/road noise level increases approximately logarithmically with speed. These targets aim at attaining the long term protection of human health ecosystems and precious resources by reducing noise levels. Reducing transport noise by up to 10 dB (A) through a systems approach including better indicators and improvements to vehicles, tyres and infrastructure is in progress. Acoustic engineers have worked in the vehicle and tyre industries in many decades with the aim to reduce or at least limit noise. Many governments have agreed on regulations and directives that limit the maximum noise emission levels from vehicles.

4.1.3 GLOBAL ROAD TRANSPORT: FUTURE NOISE TRENDS

Actual traffic noise should have significant reductions necessary if people living near busy roads are to enjoy recommended community noise levels. The challenge in the future is to...
FIG 4.11 DISTRIBUTION OF CO IN DIFFERENT INDIAN CITIES [12]

GRID-WISE INCREASE IN CO EMISSION FROM ALL SOURCES (2001-2011)

TOTAL = 31.63 Tg/ decade
GROWTH = 52%

FIG 4.12 CONCENTRATION OF RSPM IN RESIDENTIAL AND INDUSTRIAL AREAS IN MAJOR CITIES IN INDIA [13]
The technology solutions and research agenda for emission reduction for meeting these norms are elaborated in Table 4.5 and 4.6 below.

### TABLE 4.5 EMISSION REDUCTION TECHNOLOGIES

<table>
<thead>
<tr>
<th>Name of Technology</th>
<th>Description</th>
<th>Remarks</th>
<th>Investment required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine Downsizing</td>
<td>Reducing size of the engine for achieving same power</td>
<td>Technology used for SUVs and LCVs</td>
<td>Nil</td>
</tr>
<tr>
<td>Engine Down speeding</td>
<td>Reducing speed of the engine for achieving same power</td>
<td>Technology used for SUVs and LCVs</td>
<td>Nil</td>
</tr>
<tr>
<td>Mild Hybridization</td>
<td>Incorporation of electric battery and motor to supplement the IC Engine</td>
<td>Used for some luxury cars and being introduced for small cars, SUVs.</td>
<td>Investment required to develop mild hybrid vehicles</td>
</tr>
<tr>
<td>Use of Two staged turbocharging</td>
<td>Use of advanced turbocharging for better performance and lower emissions</td>
<td>Used for some passenger cars</td>
<td>Technology needs to be imported</td>
</tr>
<tr>
<td>Advanced controls</td>
<td>Advanced electronic controls with sensors and ECUs</td>
<td>Used for LCV and HCV vehicles</td>
<td>Investment required to develop low cost electronics for all vehicles</td>
</tr>
<tr>
<td>Alternative combustion</td>
<td>Use of HCCI, PCCI and other alternative combustion techniques</td>
<td>Used for some passenger cars and SUVs</td>
<td>Investment required to develop superior combustion techniques</td>
</tr>
<tr>
<td>Fuel Injection Pressure</td>
<td>Increasing fuel injection pressure in advanced common rail engines</td>
<td>Used for all vehicles</td>
<td>Technology needs to be imported.</td>
</tr>
<tr>
<td>Energy management</td>
<td>Recapturing wasted energy in braking</td>
<td>Used for Passenger Cars</td>
<td>Investment required for Technology development in India</td>
</tr>
<tr>
<td>EGR</td>
<td>Nox reduction by using exhaust gas recirculation (EGR)</td>
<td>Used for all vehicles</td>
<td>Nil</td>
</tr>
<tr>
<td>After treatment</td>
<td>Use of Three way catalyst, Diesel oxidation catalyst, Diesel Particulate Filter, Lean NOx Trap or Selective Catalytic Reduction</td>
<td>Used for all vehicles to reduce CO, HC, NOx and PM</td>
<td>SCR technology needs to be imported</td>
</tr>
<tr>
<td>VVA and VON</td>
<td>Variable Valve actuation (VVA) and variable orifice nozzle (VON) for reducing emissions</td>
<td>Used for passenger cars</td>
<td>Technology to be imported</td>
</tr>
<tr>
<td>Alternative Fuels</td>
<td>Reduction in CO and HC emissions</td>
<td>Used for 3 wheelers, PCS, SUVs and HCVs</td>
<td>Investment required to develop alternative fuel technologies</td>
</tr>
</tbody>
</table>
create a sustainable acoustical environment around roads and streets, in a time of continued traffic growth, building of more roads and streets, and with a likely continued trend towards larger and more powerful vehicles on the roads. It is difficult to imagine a development in that direction without the use of more stringent vehicle and tyre/road noise emission limits. Some new technologies for sound reduction in vehicles is improving the shape of the combustion chamber; encapsulation or shielding of entire engines or especially noisy parts of them. Use of hood blankets or laminated covers and sound absorptive material in the engine compartment. Optimization of the stiffness of the cylinder block and usage of structure-borne noise reducing materials.

4.14 NOISE TRENDS IN INDIAN ROAD TRANSPORT
Urban traffic noise in India is one of the most critical types of noise and normally considered more interfering than the other types of noises. The major cause of noise pollution is the sound coming from the horns and sirens of the vehicles continuously been activated day in and day out along the roads. The noise levels have been broadly classified under four categories by Ministry of Environment and Forests vide The Noise Pollution (Regulation and Control) Rules, 2000, figure 4.13.

Most of the community, especially in the Indian subcontinent, is not aware that noise can cause any health damages and in contrast, studies globally, has provided significant evidence that
Environmental noise and especially road traffic-generated sound have severe negative impact on human health. Currently, limited research exists on the exposure-effect studies of road traffic noise in the Indian scenario, with most reporting the noise quality only. Noise reduction system that uses active force cancellation is being used by the world’s major automobile manufacturers. In the past, attempts to reduce the effects of noise and vibration in vehicles have been based on passive technology and the use of elastomeric springs for isolation. Some vehicle manufacturers want to tune the sound to create a desirable sound quality with specific harmonics. This is the introduction of noise in electric and hybrid vehicles which are quiet in operation and may cause a potential threat to disabled persons on the road. Acoustic material technologies can also be used for noise reduction in vehicles. Figure 4.7 shows some noise control technologies.

### 4.15 Gaps in Noise Research
Development of low noise powertrains is an important area for research. Pass by noise from vehicles needs to be reduced by designing superior silencers and damping engine noise. Techniques like acoustic holography should be used for development of low noise powertrains. Acoustic enclosures along the highways to control pass by noise are some of the requirements for future noise control. Tyre noise needs to be reduced by developing high quality tyres. Road surface quality should also be improved. Noise introduction in quiet electric vehicles is another important area of research.
## TABLE 4.7 NOISE CONTROL TECHNOLOGIES

<table>
<thead>
<tr>
<th>Name of Technology</th>
<th>Description</th>
<th>Remarks</th>
<th>Investment Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vibration Dampers</td>
<td>Vibration Dampers are used to eliminate or reduce structural resonance and vibration</td>
<td>Technology used for all vehicles</td>
<td>Investment required for indigenous development</td>
</tr>
<tr>
<td>Sound Absorbers</td>
<td>Sound Absorbers are primarily used to soak up mid band and high frequency airborne sound and reflect thermal energy</td>
<td>Technology used for all vehicles</td>
<td>Investment required for indigenous development</td>
</tr>
<tr>
<td>Sound Barriers</td>
<td>Sound Barriers are used to block and reflect high energy airborne sound like road noise in the form of exhaust, airflow, drivetrain and tire noise</td>
<td>Technology used for all vehicles</td>
<td>Technology needs to be imported</td>
</tr>
<tr>
<td>Gasketing Materials</td>
<td>Gasketing Materials are used to eliminate squeaks, rattles and buzzes and to seal speakers</td>
<td>Technology used for all vehicles</td>
<td>Investment required for indigenous development</td>
</tr>
<tr>
<td>Engine Harmonic Cancellation (EHC)</td>
<td>EHC uses vehicle’s audio system to produce a signal acoustically opposite to the undesirable sound and effectively reduce it</td>
<td>Technology used for passenger cars</td>
<td>Technology needs to be imported</td>
</tr>
<tr>
<td>Acoustic Holography</td>
<td>Used for virtual Noise mapping</td>
<td>Technology used for all vehicles</td>
<td>Technology needs to be imported</td>
</tr>
<tr>
<td>Anechoic Chambers</td>
<td>Used for experimental Noise mapping</td>
<td>Technology used for all vehicles</td>
<td>Investment required for indigenous development</td>
</tr>
</tbody>
</table>
REFERENCES

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7. (http://www.unep.org/transport/gfei/autotool/basic.asp)
8. International: IMO Marine Engine Regulations (www.dieselnet.com)
9. MLIT, Japan (http://www.libralato.co.uk/society/peakoil.html)
13. Ghude S.D., “Regional Distribution of Pollution in India” Indian Institute of Tropical Meteorology (IITM), Pune.
5.0 VEHICLE TECHNOLOGY ISSUES

Road network moves people and goods around and makes a major contribution to the economy. It is used for work, education, shopping, and leisure and is also used widely in every aspect of life. Road network supports various transport modes such as bicycles, motorbikes, cars, buses, vans and HCVs. There are a number of requirements for owning, operating and driving vehicles. These include licenses for drivers of HCV and bus operators, stringent driving tests and road safety instructions and standards, safety of trucks and buses and approvals for vehicle designs and components. These services may not always be fully visible, but they touch the lives of every individual, every day in one way or the other. All these measures ensure that all road users including the occupants of the vehicles and the pedestrians on the roads are safe.

5.1 GLOBAL POWER-TRAIN DEVELOPMENT TRENDS

Two major streams of technology in SI engine are 2-stroke and 4-stroke technologies. 2-stroke engine technologies have been popular since the 1990s mainly due to their simplicity and low cost. However, 2-stroke technology is being phased out in favor of the more fuel efficient 4-stroke engine technology. The 2-wheelers are moving from carburetion to fuel injection technologies, due to more efficient control of fuelling thereby resulting in better fuel economy, higher power and lower emissions. The evolution of two and three wheeler segment, SI engine technologies used till date is shown in figure 5.1.

Both, the passenger car and SUV segment use SI and CI engine technologies. The SI
### FIGURE 5.2: EVOLUTION OF PASSENGER CAR SI ENGINE TECHNOLOGIES

<table>
<thead>
<tr>
<th>Year</th>
<th>HC + NOx, g/km</th>
<th>CO, g/km</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>1998</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>BSI 2000</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>BSII 2000</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>BSIII 2005</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>EURO IV</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

#### BHARAT STAGE I
- Intake, exhaust, combustion optimization
- Carburetor optimization
- Air injection
- Catalytic converter

#### BHARAT STAGE II
- Fuel injection
- 3-W Catalytic Converter
- Fixed EGR
- CNG/LPG

#### BHARAT STAGE III
- Fuel injection
- Catalytic Converter
- Variable EGR
- Variable valve timing
- Multi valve
- CNG/LPG

#### BHARAT STAGE IV
- Direct
- In-cylinder injection
- Multi-brick catalytic converter
- Lean burn
- Electric/Hybrid Vehicles

### FIGURE 5.3: EVOLUTION OF COMMERCIAL VEHICLE CI ENGINE TECHNOLOGIES

<table>
<thead>
<tr>
<th>Year</th>
<th>NOx, g/kWh</th>
<th>CO, g/kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>1992</td>
<td>0.5</td>
<td>0.4</td>
</tr>
<tr>
<td>1996</td>
<td>0.4</td>
<td>0.3</td>
</tr>
<tr>
<td>BSI 2000</td>
<td>0.3</td>
<td>0.2</td>
</tr>
<tr>
<td>BSIII ETC 2005</td>
<td>0.2</td>
<td>0.1</td>
</tr>
<tr>
<td>BSIII ESC 2005</td>
<td>0.1</td>
<td>0.0</td>
</tr>
</tbody>
</table>

#### BHARAT STAGE I
- Turbo charging
- Inter cooling (based on specific power)
- Moderate swirl
- Injection pressure> 800 bar
- Rotary pump
- VCO nozzle
- Conversion to CNG/LPG

#### BHARAT STAGE II
- Turbo & inter cooling
- Multi valve/ 2 valve
- Low swirl
- Injection pressure> 1200 bar
- Unit injector/ common rail injection/ Rotary pump
- Injection rate shaping
- Oxycat
- Electronic injection control

#### BHARAT STAGE IV
- Multi valve
- NOx Trap
- Particulate trap
- Common rail injection
- Injection pressure>1600 bar
- On-board diagnostic system
- VGT
- Cooled EGR

---

#### Diesel Engines
- Optimized ports, combustion chambers
- Turbo charging
- Moderate to high injection pressures [600-800 bar]
- Inline/rotary
engine technologies used for passenger cars are captured in figure 5.2. It can be noted that the passenger car engine technologies have completely shifted from carburetion to fuel injection. Currently, single point and multipoint injection (MPFI) technologies are in use. The future trend is to move towards Gasoline Direct Injection (GDI) technology. Further, incorporation of technologies such as Exhaust Gas Recirculation (EGR), CNG-LPG, Multilayer Catalytic Converters will improve fuel economy and reduce emissions.

For heavy-duty vehicles, diesel engine technologies shifted completely from Indirect Injection (IDI) to Direct Injection (DI). Further, Common Rail Direct Injection (CRDI) technology was introduced. The future trend is a move towards higher pressure CRDI technology. Incorporation of advanced technologies such as EGR, turbo-charging, multi-valve and after-treatment systems like Diesel Oxidation Catalyst (DOC) and Diesel Particulate Filter (DPF) is inevitable. Compression Ignition (CI) engines for passenger cars will move towards CRDI. Technologies such as thermal management, down-sizing, advanced after-treatment and hybridization will be used in future. Modern HCV and LCV engines require higher specific power and torque output with faster response, lower fuel consumption and reduced emissions. The evolution of CI engine technologies used for light and heavy commercial vehicles are shown in figure 5.3.

5.2 FUTURISTIC INTERNAL COMBUSTION ENGINE AND TRANSMISSION INNOVATIONS

Advanced combustion technology such as Homogeneous Charge Compression Ignition (HCCI) and Partially Premixed Charge Compression Ignition (PCCI) are being considered as alternative combustion concepts in the IC engines. A state-of-the-art IC engine concept, HCCI/PCCI has potential for nearly zero NOx and soot emissions with efficiency equivalent/higher than CI engines. Due to fuel flexibility offered by HCCI/PCCI combustion concepts, alternative fuels such as primary alcohols, and biodiesel can be used in these engines. HCCI combustion has characteristics of the two most popular forms of combustion used in IC engines, namely Homogeneous Charge Spark Ignition (Gasoline engines) and Stratified Charge Compression Ignition (Diesel engines). This is a novel engine technology which has potential to substantially lower emissions from IC engines. These engines operate on a dilute, premixed charge that reacts and burns volumetrically throughout the cylinder as it is compressed by the piston. HCCI incorporates the best features of both spark ignition (SI) and compression ignition (CI) engines. As in an SI engine, the charge is well mixed, which minimizes particulate emissions, and as in a CI engine, the charge is ignited by compression and has no throttling losses, which lead to high thermal efficiency.

Table 5.1 list some of the Powertrain technologies. The research agenda for IC engines and transmission system innovation is given in table 5.2. This table also outlines the roadmap for innovations in Indian automotive sector.
<table>
<thead>
<tr>
<th>Name of Technology</th>
<th>Description</th>
<th>Remarks</th>
<th>Investment Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPFI</td>
<td>Multipoint fuel injection</td>
<td>Technology used for 3 wheelers, passenger cars, LCVs and HCVs</td>
<td>Investment required for indigenous development</td>
</tr>
<tr>
<td>GDI</td>
<td>Gasoline Direct Injection</td>
<td>Technology used for Passenger cars, LCVs and HCVs</td>
<td>Investment required for indigenous development</td>
</tr>
<tr>
<td>CRDI</td>
<td>Common Rail Direct Injection</td>
<td>Technology used for 3 wheelers, passenger cars, LCVs and HCVs</td>
<td>Technology can be imported</td>
</tr>
<tr>
<td>Engine Downsizing and De-rating</td>
<td>Reducing size of the engine for achieving same power or reducing power from same size</td>
<td>Technology used for SUVs and LCVs</td>
<td>Nil</td>
</tr>
<tr>
<td>Hybridization</td>
<td>Incorporation of electric battery and motor to supplement the IC Engine</td>
<td>Used in some luxury cars and being introduced for small cars, SUVs</td>
<td>Investment required to produce low cost electronics and batteries</td>
</tr>
<tr>
<td>Advanced Combustion</td>
<td>Advanced combustion concepts like HCCI, PCCI etc.</td>
<td>Technology used for SUVs and LCVs</td>
<td>Investment required for indigenous development</td>
</tr>
<tr>
<td>Variable Compression, Variable Valve Lift</td>
<td>Variable concepts in engines for higher fuel efficiency and performance</td>
<td>Used in some luxury cars and being introduced for small cars, SUVs</td>
<td>Technology can be imported</td>
</tr>
<tr>
<td>High Performance Engine Materials</td>
<td>Advanced materials like plastics, ceramics, high strength alloys etc.</td>
<td>Used in some luxury cars and being introduced for SUVs</td>
<td>Investment required for indigenous development</td>
</tr>
<tr>
<td>Combustion Modeling</td>
<td>Computational Fluid. Dynamics (CFD) and chemical kinetic modeling</td>
<td>Used for all types of engine development</td>
<td>Investment required for development of software and workstation facilities</td>
</tr>
<tr>
<td>Powertrain Electronics and Sensors</td>
<td>Used for advanced engines like CRDI, GDI etc.</td>
<td>Used for all advanced engines</td>
<td>Technology can be imported</td>
</tr>
</tbody>
</table>
## TABLE 5.2 RESEARCH AGENDA FOR IC ENGINES AND TRANSMISSION INNOVATIONS

<table>
<thead>
<tr>
<th>Short Term (1-5 Years)</th>
<th>Medium Term (5-10 Years)</th>
<th>Long Term (10-15 Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine downsizing by using boost i.e. by using turbocharging and supercharging</td>
<td>Automatic Transmission</td>
<td>Solar powered cars/ electric personalized transport/ small and safe cars for two passengers</td>
</tr>
<tr>
<td>Direct injection technology</td>
<td>Increasing bio-content in fuels</td>
<td>Hydrogen mixed with CNG (upto 30%) for natural gas engines</td>
</tr>
<tr>
<td>Variable valve actuation system</td>
<td>Bespoke engines for HEV and PHEV</td>
<td>Novel thermodynamic cycles for higher energy utilization</td>
</tr>
<tr>
<td>Dual clutch transmission system</td>
<td>Advanced combustion technology such as HCCI/CAI</td>
<td>Novel concepts and system design to utilize the exhaust gas recovery</td>
</tr>
<tr>
<td>Friction reduction interventions, efficient power packs</td>
<td>Exhaust gas heat recovery</td>
<td></td>
</tr>
<tr>
<td>Planting of dense trees around roads to control noise and active CO₂ sequestration</td>
<td>Higher blending with bio-content fuels</td>
<td></td>
</tr>
<tr>
<td>Engine cut off technology</td>
<td>Advanced powertrain controls</td>
<td></td>
</tr>
<tr>
<td>Advanced combustion technology such as GDI</td>
<td>Strict emission laws for CO₂ emissions, particulate number and size distribution</td>
<td></td>
</tr>
</tbody>
</table>

**Figure:**
- Short Term (1-5 Years)
- Medium Term (5-10 Years)
- Long Term (10-15 Years)
Propulsion systems is one of the important components for improving the vehicles efficiency. The research agenda for improvement in the propulsion systems and research agenda for vehicle efficiency improvement are given in Table 5.3 and 5.4 respectively.

**TABLE 5.3 RESEARCH AGENDA FOR PROPULSION SYSTEMS**

<table>
<thead>
<tr>
<th><strong>SHORT TERM (1-5 YEARS)</strong></th>
<th><strong>MEDIUM TERM (5-10 YEARS)</strong></th>
<th><strong>LONG TERM (10-15 YEARS)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>IC engine optimization for fuel saving and performance improvement</td>
<td>Development of bespoke engines for high efficiency plug-in hybrid electric vehicles (PHEV)/range extender EV</td>
<td>Introduction of fuel cell drive trains</td>
</tr>
<tr>
<td>Engine size, mass, and friction reduction by using advanced boost systems and variable valve actuation</td>
<td>Intake air management including capacitive boosting</td>
<td>Super high efficiency electric machines and use of superconductors</td>
</tr>
<tr>
<td>Flexible valve/actuators for engines/transmission losses and improvement of actuation</td>
<td>Lower cost and compact design electric motors: After successful implementation of e-motors, continuous research is required for their cost and size reduction to make them more attractive and economical.</td>
<td>Advanced materials for electric machines and improved fuel cell drive trains</td>
</tr>
<tr>
<td>Low-cost compact electric motors for fuel saving</td>
<td>Heat energy recovery (E-turbine): The exhaust gases contain a large amount of thermal energy. This energy can be used to drive various on-board devices. The high velocity of exhaust gas helps in boosting the engine while its temperature can be used for intake air conditioning. Peltier coolers can be used to utilize waste exhaust energy in the exhaust system which can be used for charging the batteries.</td>
<td>Advanced heat energy recovery technologies (such as thermoelectric)</td>
</tr>
<tr>
<td>IC engine optimization for fuel saving and performance improvement</td>
<td>New thermodynamic cycles for engines with overall thermal efficiency greater than 70%</td>
<td></td>
</tr>
<tr>
<td>Improvement of IC engine thermal efficiency by more extreme downsizing, modified thermodynamics cycles etc.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Development of electrical actuation systems: For efficient working of IC engine, it is required to reduce the number of mechanical systems as much as possible. These systems can be reduced by using electrical actuators, which greatly enhance the efficiency however they also increase system complexity</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The research agenda for improvement in the propulsion systems and research agenda for vehicle efficiency improvement are given in Table 5.3 and 5.4 respectively.
TABLE 5.4 RESEARCH AGENDA FOR VEHICLE EFFICIENCY IMPROVEMENT

<table>
<thead>
<tr>
<th>RESEARCH AREA</th>
<th>TARGET</th>
<th>TIMELINE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduction of vehicular weight through innovative designs, advanced materials, vehicle structures, development of light weight interiors and components, as well as through the use of advanced manufacturing technologies such as joining, welding etc.</td>
<td>SHORT TERM (1-5 YEARS)</td>
<td></td>
</tr>
<tr>
<td>Reduction of losses in brakes due to the friction. Regenerative braking systems and hydraulic systems are few of them however they need improvement from the present state-of-the-art.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduction in vehicular drag by improvement in exterior design concepts. By using aerodynamic designs, fuel saving can be up to 20%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Advanced aerodynamic concepts for drag reduction</td>
<td>MEDIUM TERM (5-10 YEARS)</td>
<td></td>
</tr>
<tr>
<td>Solar energy driven vehicle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Development of flexible re-configurable multi-utility vehicle</td>
<td>LONG TERM (10-15 YEARS)</td>
<td></td>
</tr>
<tr>
<td>Reduction of vehicle weight up to 50% of the short-term target</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5.3 VEHICLE CONTROL SYSTEM INNOVATIONS

Information enabled control (Topology, Vehicle to vehicle communication, Vehicle to instrument communication, traffic etc.) is emerging as an important feature for urban and highway transportation system. It will help in safe journey with improved vehicle safety. A combined system of manual and automatic responses can also be used for optimization of different control systems. These efforts are aimed at demonstrating the concepts of a new class of road related services (such as those related to traffic management and mobile electronic payments) for both safety and convenience.

Research is required for modernization of traffic management system. The highway traffic management control (HTMC) system collects data in real time, calculates current traffic status, estimates future demand and processes the data to extract the information required by the roadway controller which, in turn, generates commands for ramp metering, speed limit distributions at various sections of the highway as well as generates routing instructions for vehicles. The speed limits and routing instructions could be communicated directly to each vehicle in a more advanced system or via variable message sign boards along the highway. The HTMC system can be designed to be flexible to operate at various levels of current and future technology.

Research agenda for vehicle safety control is mentioned in table 5.5.
5.4 ELECTRIC MOBILITY INNOVATIONS

There is likely to be an increase in the use of alternative fuels in near future as new technologies are being developed at a fast pace. The only challenge is to make them affordable. Promising technology prototypes exist but most are at an early concept stage. These technologies include fuel-cells, biofuels and hydrogen. Electric vehicles are being developed, which have driving range several times higher than their earlier versions. They are beginning to capture a small part of the passenger and urban car market in India. Non-availability of lighter and high capacity batteries and associated technology however remains a big hurdle in electric mobility. Efforts are being made in this direction and trials of new battery and charging technologies are being undertaken. Innovative solutions are being devised to extend the range of electric cars. The accessibility of car charging points through smart grids and inductive charging is being enhanced and suitable infrastructure is being created in cities. However, at present, electric cars which are in commercial production, typically have a range of upto 300 Kms and are required to be charged overnight before they can be used again next day. Therefore, they essentially remain an intra-city transport mode. The Society of Motor Manufacturers and Traders (SMMT) expects electric vehicles to remain a small part of the market for many years to come.

TABLE 5.5 RESEARCH AGENDA FOR VEHICLE SAFETY CONTROL

<table>
<thead>
<tr>
<th>Research Agenda</th>
<th>Timeframe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information enabled control [e.g. of Topology, Vehicle to vehicle communication, Vehicle to instrument communication, traffic etc.]</td>
<td>Short Term (1-5 Years)</td>
</tr>
<tr>
<td>Development of hardware and control systems to optimize in-vehicle energy management</td>
<td></td>
</tr>
<tr>
<td>Reduction of parasitic losses from ancillary equipment by appropriate maintenance</td>
<td></td>
</tr>
<tr>
<td>Intelligent thermal management</td>
<td></td>
</tr>
<tr>
<td>Development of hardware and control systems to optimize in-vehicle energy management</td>
<td></td>
</tr>
<tr>
<td>Reduction of parasitic losses from ancillary equipment by appropriate maintenance. All these components reduce engine efficiency by consuming large amount of power in the compressor and other moving components</td>
<td></td>
</tr>
<tr>
<td>Demonstration of information enabled control at vehicle level for routing, energy management and safety</td>
<td></td>
</tr>
<tr>
<td>Vehicle energy management [Direct and indirect]</td>
<td>Medium Term (5-10 Years)</td>
</tr>
<tr>
<td>Power train optimization for recognized routes</td>
<td></td>
</tr>
<tr>
<td>Intelligent power train and heating ventilation and air conditioning (HVAC) management</td>
<td></td>
</tr>
<tr>
<td>Autonomous powertrain and vehicle control</td>
<td></td>
</tr>
<tr>
<td>Control systems integrated with active safety systems</td>
<td>Long Term (10-15 Years)</td>
</tr>
</tbody>
</table>
The growing environmental concern and carbon dioxide emissions have catalyzed the growth of electric vehicles globally. In India, electric vehicles are already making a mark in the transportation sector. Many domestic automotive manufacturers such as Mahindra REVA, and Eko Scooters are embarking on electric transportation programs to combat air pollution in India. India’s National Council for Electric Mobility (NCEM) has adopted the National Electric Mobility Mission Plan 2020 (NEMMP 2020), which lays the vision, sets the targets and provides the roadmap for achieving significant penetration of electric vehicles (including hybrids) in India by 2020. The NEMMP 2020 has set a target of 6-7 million units of new vehicle sales of full range of electrified vehicles, along with resultant savings of liquid fuel of 2.2 – 2.5 million tonnes to be achieved in 2020. It is estimated that the total investment required will be in the range of Rs 20,000-23,000 crores (US$3.6–$4.1 billion) over the next 5-6 years. Battery-powered EVs use an electric motor for propulsion with batteries for electricity storage. Figure 5.4 shows the landscape for technologies for electric mobility and Table 5.6 lists various technologies for electric mobility.
<table>
<thead>
<tr>
<th>Name of Technology</th>
<th>Description</th>
<th>Investment Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery</td>
<td>High capacity Lithium ion/ Ni-MH (Nickel Metal Hydride)/ Lithium-air batteries are required.</td>
<td>Investment required for developing low cost, long life superior batteries alongwith high power density and high efficient motor</td>
</tr>
<tr>
<td>Battery Management</td>
<td>Proper operation of batteries</td>
<td>Technology to be developed for Indian operating conditions</td>
</tr>
<tr>
<td>Power Electronics</td>
<td>Electronic components required for EV and HEVs</td>
<td>Investment required for technology development in India</td>
</tr>
<tr>
<td>Electric Motor</td>
<td>Propulsion motor</td>
<td>Investment required for developing low cost, long life motors</td>
</tr>
<tr>
<td>Ultra capacitor</td>
<td>Electrical energy storage</td>
<td>Technology can be imported in short-term can be developed for long-term</td>
</tr>
<tr>
<td>Transmission for EVs and HEVs</td>
<td>Transmission of power and is coupled to engine for hybrid electric vehicle</td>
<td>Investment required for developing superior transmission systems</td>
</tr>
<tr>
<td>Electronic control units</td>
<td>For control of various operations such as engine, air conditioning, safety, emissions etc.</td>
<td>Investment required for developing low cost, long life ECUs</td>
</tr>
<tr>
<td>Sensors</td>
<td>Sensors for providing feedback for various control operations</td>
<td>Investment required for developing low cost, long life superior sensors</td>
</tr>
<tr>
<td>Charging Infrastructure</td>
<td>Public Chargers, Quick change battery stations</td>
<td>Investment required for developing charging infrastructure</td>
</tr>
</tbody>
</table>
5.4.1 BATTERY FOR ELECTRIC VEHICLES

Battery is the vital component for energy storage on-board. Battery technology was first used in electric vehicles during 19th century, and then batteries were mass produced in early 20th century for use in ignition systems, headlamps, windshield wipers. Battery technology has made enormous progress with advancement in terms of science and engineering. Their energy density has been significantly improved through advancements in electro-chemistry. New composite materials have improved battery packaging thus making them smaller, more amenable to reuse and recycling, and virtually maintenance-free.

EVs substitute a battery (or other device capable of storing electricity in some form) and an electric motor for the gasoline tank, IC engine and transmission system of a conventional vehicle. Although batteries can store only a small fraction of the energy in the same weight and volume of gasoline, EVs may gain over this disadvantage because of their excellent efficiency. Conventional IC engine vehicles use roughly 10.8% of the fuel during braking and at idling, when the engine really does not contribute to useful work. Electric motors need not operate during EV braking and idling, thereby leading to energy savings. Most of the accessories used in an IC engine powered cars, such as the water pump, oil pump, cooling fan, and alternator can be eliminated if battery heat losses are not high, because motor and electronics cooling requirements do not require much power. In addition, the hydraulic power steering in a conventional vehicle must be replaced by electric power steering, which consumes only a fraction of the power of a conventional system. Also, some of the energy lost during braking can be recovered by an EV, because the motor can act as a generator when it absorbs power from the wheels. The energy can be stored in the battery and later released to drive the motor. The energy lost to the brakes in a car is about 35% of total traction energy.

The focus today is on batteries with alternative materials such as Lithium ion (Li-ion) and Lithium polymers. Initial research at MIT shows that Lithium air battery has a great promise for future energy storage domains. Theoretically such battery could hold more than four times energy that the Lithium ion battery. However, as of now, this is far from commercialization. At vehicle level, batteries are important components in an electrical power management system, whose objective is to manage power generation, storage, distribution, consumption and regeneration efficiently. Such systems include one or more batteries, an alternator, electrical power cables, and junction boxes with microprocessors for power management. There is a great scope for research in electrical mobility and table 5.7 shows the research agenda for electric mobility in India.

<table>
<thead>
<tr>
<th>TABLE 5.7 RESEARCH AGENDA FOR ELECTRICAL MOBILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SHORT TERM (1-5 YEARS)</strong></td>
</tr>
<tr>
<td>Development of low speed, high torque DC motors as well as Brushless Direct Current (BLDC) for personalized electric mobility</td>
</tr>
<tr>
<td>Regenerative braking system for battery charging</td>
</tr>
<tr>
<td><strong>MEDIUM TERM (5-10 YEARS)</strong></td>
</tr>
<tr>
<td>Development of efficient power electronics for electrical mobility</td>
</tr>
<tr>
<td><strong>LONG TERM (10-15 YEARS)</strong></td>
</tr>
<tr>
<td>Research for long life, high capacity, lighter batteries and its commercial production</td>
</tr>
<tr>
<td>Use of Peltier devices to charge the batteries using waste heat of exhaust gases</td>
</tr>
<tr>
<td>Lithium air battery</td>
</tr>
</tbody>
</table>
Prioritized fields of activity in the area of electrical vehicles, technology, area of application and vehicle class are shown in figure 5.6.

**FIG 5.6 **PRIORITIZED FIELDS OF ACTIVITY IN THE AREA OF ELECTRICAL VEHICLES

<table>
<thead>
<tr>
<th>APPLICATION</th>
<th>VEHICLE CLASS</th>
<th>TECHNOLOGY</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMMUTERS</td>
<td>TWO-WHEELERS</td>
<td>Battery EV</td>
</tr>
<tr>
<td></td>
<td>CARS</td>
<td>HEV (optional SOFC as APU)</td>
</tr>
<tr>
<td>Taxis</td>
<td>CARS</td>
<td>Plug-in HEV</td>
</tr>
<tr>
<td>Public Fleets</td>
<td>Heavy Trucks</td>
<td>Battery EV</td>
</tr>
<tr>
<td></td>
<td>Light Trucks</td>
<td>Fuel Cell EV</td>
</tr>
<tr>
<td>Company Fleets</td>
<td>CARS</td>
<td>Plug-in HEV</td>
</tr>
<tr>
<td></td>
<td>Light Trucks</td>
<td>Battery EV</td>
</tr>
<tr>
<td>Recreational Traffic</td>
<td>Bicycles</td>
<td>Battery EV</td>
</tr>
<tr>
<td>Public Transport User</td>
<td>Buses</td>
<td>Fuel Cell EV</td>
</tr>
</tbody>
</table>
5.5 RESEARCH AGENDA FOR MICRO-HYBRIDS, FULL HYBRIDS, PLUG-IN HYBRIDS AND FUEL CELL VEHICLES

The most promising application of electric mobility, however, is in the hybrid vehicles, which uses a combination of electrical motor and a smaller IC engine along with novel concepts such as regenerative braking. Hybrid Electric Vehicles (HEVs) use both an engine and motor with sufficient battery capacity (typically 1 kWh to 2 kWh). Both store electricity generated by the engine or by brake energy recovery. Research is required to develop low cost, long-life sensors and controllers for hybrid electric vehicles.

Some of the important areas for hybrid technology, which can be developed in short-term/medium term and long term timeframe, are given in table 5.8. Research Agenda for Micro-Hybrids, Full Hybrids and Plug-in Hybrids are given in table 5.9, 5.10 and 5.11 respectively.

**TABLE 5.8 RESEARCH AGENDA FOR HYBRIDS**

- **SHORT TERM (1-5 YEARS)**
  - Reduction of cost/kW and kW/liter of electric drives and power electronics for hybrid electric vehicle (HEV) configurations
  - Development and demonstration of battery technology with high specific energy, high energy density and long life cycle for mass production by improving the battery quality/durability greater than 200 Wh/kg
  - Development of low cost power electronics is required for superior control and smooth running of moving components
  - In-field trials of EV charging infrastructure (using localized fleets)
  - Development and demonstration of next generation battery technology:
    a. High energy density for EV and PHEV applications
    b. With high specific energy
    c. Reduced cost and lighter batteries by using advanced materials

- **MEDIUM TERM (5-10 YEARS)**
  - Flexible battery management system
    (Adaptable to many cell types and pack configurations)
  - Alternative energy recovery and storage systems - mechanical, chemical etc.
  - Development of advanced hybrid system: Hybrid vehicles combine two energy sources with an electric drive-train, with one or both sources providing power to the wheels.

- **LONG TERM (10-20 YEARS)**
  - 3rd generation batteries with specific energy greater than 400 Wh/kg.
  - New low cost solid state power conversion systems.
### TABLE 5.9 RESEARCH AGENDA FOR MICRO HYBRIDS

**SHORT TERM (1-5 YEARS)**
- Belt mounted and crank mounted starter generator
- 12V battery system for smaller engines
- 24-42V battery system for larger engines
- Small Pb (+Li-ion) batteries
- Larger, crank mounted electric machines offering mild hybrid functionality
- Increased voltage (40-150V)
- Li-ion battery with minimized cost and weight

**MEDIUM TERM (5-10 YEARS)**
- Development of new hybrid fuels e.g. JP8 used by US Army

### TABLE 5.10 RESEARCH AGENDA FULL HYBRIDS

**SHORT TERM (1-5 YEARS)**
- Cost minimization and maximization of battery life
- Li-Ion batteries

**MEDIUM TERM (5-10 YEARS)**
- Development of sufficient electricity storage towards replacement of gasoline engines with PHEV or EV

**LONG TERM (10-20 YEARS)**
- Development of full bespoke hybrid power trains
- Introduction of modular hybrids in larger vehicle with diesel as well as gasoline
5.6 CURRENT INTELLIGENCE TRENDS IN GLOBAL ROAD TRANSPORT

Intelligent Transport Systems play an important role in shaping the future ways of mobility and the transport sector. Through the use of ITS applications, transport will become more efficient, safer and greener. The huge potentials and benefits, however, can only be reaped if ITS solutions are put in place and harmonized internationally to the extent possible. The urbanized life of the 21st century will rely heavily on urban transportation. Individual lifestyles, flexible work rhythms and unconstrained leisure time activities ensure that future of transportation will rely on super-intelligence in vehicles, control systems and planning tools. Super-intelligence implies that the intelligence of the system as a whole reaches higher levels, because of the integration of intelligence in all the components of the system, viz., vehicles, infrastructure, control system, commuters, cargo and enablers of information all of them intelligent.

**TABLE 5.11 RESEARCH AGENDA FOR PLUG-IN HYBRIDS**

<table>
<thead>
<tr>
<th>MEDIUM TERM (5-10 YEARS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Development of energy storage technology which is compatible with range and recharging requirements</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LONG TERM (10-15 YEARS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Move towards range extended EV with auxiliary power unit (APU)</td>
</tr>
<tr>
<td>Development of IC engine component compatible with increasing bio/synthetic fuel content</td>
</tr>
<tr>
<td>Development of energy storage (low power/energy)</td>
</tr>
</tbody>
</table>

**TABLE 5.12 RESEARCH AGENDA FOR FUEL CELL VEHICLES**

<table>
<thead>
<tr>
<th>SHORT TERM (1-5 YEARS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Availability and distribution of clean hydrogen</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MEDIUM TERM (5-10 YEARS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research for low cost hydrogen storage systems</td>
</tr>
<tr>
<td>Initial introduction most likely as evolution of range extended EV/plug-in hybrid</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LONG TERM (10-15 YEARS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research for low cost fuel cells</td>
</tr>
<tr>
<td>Can be introduced due to better cost, range of applications, power and refueling time of hydrogen storage as compared to batteries</td>
</tr>
</tbody>
</table>
Intelligent vehicle is a wonder of computation, multiple CPUs, hundreds of miles of cabling and automatic operation. Technologies such as Automatic transmission, anti-skid braking, stability controls, adaptive cruise control, lane control, even automatic parking are the integral part of the intelligent vehicle. In addition, automatic payment for highway tolls, parking lots, and drive-through restaurants. Navigation systems, entertainment systems, HVAC systems sometimes different for each passenger are hallmarks of intelligent vehicles. These intelligent system applications impact every facet of driver experience and improve both vehicle safety and performance. Intelligent vehicle technologies although expensive, are being increasingly deployed in Europe, USA and Japan. Other applications of intelligent system design apply to adapting the vehicle to the driver’s preferences and helping the driver stay aware.

In super-intelligent vehicles, there is no need of a driver. The intelligence makes it really autonomous. Not only it drives the vehicle by itself, it also responds to signals from other vehicles or the infrastructure. Driverless public transport is already very much in mainstream. An intelligent infrastructure communicates to other aspects of the transport system. For instance, LED’s in the road surface providing warnings about incidents, self-healing concrete that enhances life span of roads and bridges, bike lanes that converts sunlight into electricity.

Smart highways include the road deck with designs such as Glow-in-the-dark Lining, Dynamic Paint, Interactive Light and Electric Priority Lane. The goal in the future would be is to make roads, which are more sustainable and interactive by using light, energy and road signs that automatically adapt to the traffic situation. Smart grids can communicate with vehicles to bring electricity to those cars and bikes, which have the biggest need. Intelligent cargo enables packages to interact with their surroundings and make context aware decisions. In this way, the planning process of cargo freight happens autonomously. For all these forms of intelligence, processing huge amount of data is crucial. When the computational power of computer processors goes up, there will be endless new opportunities for artificial intelligence.

5.7 INTELLIGENCE TRENDS IN INDIAN ROAD TRANSPORT

In India Intelligent vehicle technologies have started emerging. Intelligent vehicle technologies are used in some luxury vehicles in India, however, most of the public transport, cargo and low cost private vehicles do not have these technologies. Technologies like automatic transmission, anti-skid braking, stability controls, which have a bearing on safety are being used in India. It is expected that these technologies will be incorporated gradually in all vehicles in India along with intelligent road infrastructure.

REFERENCES

6.0 MATERIALS AND RECYCLING ISSUES

6.1 INTRODUCTION:
The quest to reduce the weight of vehicles is not new. It is safe to say that weight reduction of vehicles is an evolving field of materials and manufacturing, which offers a robust vehicle design. Reducing the overall vehicle size is the easiest way to reduce its weight. However, in reality the average vehicle weight has increased steadily since the early 1980’s due to the growing appetite for larger vehicles. These trends are expected to continue making it unlikely that light weighting can be achieved by a simple reduction in fleet vehicle size.

Another method used to reduce vehicle mass is through a complete vehicle redesign. Examples of redesign may be a switch from body-on-frame to uni-body construction or reducing non-structural elements of the vehicles. However, in many instances this is not possible. For example, changing the body construction affects the overall volume of the vehicles produced and may increase cost due to complex assembly procedures. Unlike vehicle size and content reductions, advanced light-weight materials may be introduced in the vehicle with little or no impact on the consumer. In fact, light weighting while maintaining vehicle size may actually increase the performance of the vehicle. A combination of high-strength, low cost and capability to be produced in high volumes has made mild steel a very attractive material in automotive applications. Therefore, mild steel has been a dominant material for automotive components. However, as technology changes and fuel economy acquires more importance, other materials would gain acceptance in automotive industry. As these new materials become prominent in the automotive industry, engineers and scientists would have an opportunity to explore new applications for them, further increasing their utilization.

Economic use of advanced lightweight materials for automotive construction will be enhanced by both prompt recycling of scrap materials during manufacture, as well as recycling of the end-of-life vehicles incorporating such materials. Statutory mandates in a global economy and environmental considerations also dictate a need to recover or make usable many non-metallic materials, which are currently not recycled. The development of viable strategies for control of materials of concern is also critical to enhancing recyclability.

6.2 CURRENT AND FUTURE MATERIALS TRENDS IN GLOBAL ROAD TRANSPORT
The automotive industry uses a large number of materials to manufacture vehicles, which include iron, aluminum, plastics, steel, glass, rubber, copper, and others. These parts are used to create everything from dashboard needles and wirings, to the engine block and transmission gears.

These materials have evolved greatly over last few decades, becoming more sophisticated, and safer. New automotive manufacturing technologies have emerged over the years and are used in increasingly innovative ways. Urban vehicles are becoming lighter and fuel efficient, primarily due to use of new materials such as carbon fiber, steel, aluminum, titanium, magnesium and plastics. Currently, however cost is a major criterion limiting the use of these materials. Figure 6.1 shows scenario in the automotive sector.

EU and Japan are at the forefront of using new materials in automotive sector. The potential for new materials is immense. As they allow new types of designs and improve aesthetics of the vehicles. Materials have been the backbone of the automotive industry, which is being impacted by CO\textsubscript{2} emission legislations. Engine downsizing, turbo-charging and light-weighting are the global trends in the automotive industry, which are affecting the choice of materials. A 10% reduction in vehicle weight results in a 5-7% fuel savings provided the power-train is
FIG 6.1 ROAD TRANSPORT MATERIALS SCENARIO [1]

2010

- TRADITIONAL STEEL: 72%
- ALUMINIUM: 10%
- MAGNESIUM: 1%
- PP: 6%
- PA: 2%
- PU: 1%
- ABS: 1%
- AHSS: 7%

2017

- TRADITIONAL STEEL: 52%
- AHS: 21%
- ALUMINIUM: 13%
- MAGNESIUM: 1%
- PP: 8%
- PA: 2%
- PU: 1%
- ABS: 1%
- OTHERS: 1%
downsized. Penalties for excess emissions from vehicles have ensured that manufacturers use every material as a design variable to ensure that vehicle weight is reduced, with no compromise on safety and performance. Studies on materials have shown that aluminum, advanced high-strength steel (AHSS), and some plastics like poly-propylene (PP), poly-amide (PA) and poly-urethane (PU) have emerged as preferred choices for light-weight designs. Metals, owing to their strength, recyclability and good cost-to-performance ratios have historically been the preferred choice for structural components. For a typical mid-size passenger car, metals constitute about 75% of vehicle weight, of which around 60% is traditional and high-strength steels and 7% is AHSS. Aluminum occupies ~89% by weight and is expected to exhibit healthy growth as it competes with steel and plastics in almost all components of a car. Magnesium (in alloy form), exhibiting the highest strength-to-weight ratio among structural metals, is also set to grow.

6.3 GAPS IN MATERIAL SCENARIO
Development of low cost, long-life and affordable materials is important. Development of high strength steel alloys is required. Materials should be developed for energy absorbing characteristics in view of safety requirements. Light-weight materials like aluminum and magnesium should be used for vehicular components, including power-train to improve fuel economy. Research on new materials like composites should be explored. Use of natural fibers like Jute is required for automotive components.

6.4 ROADMAP FOR MATERIALS IN TRANSPORT SECTOR
Indian vehicles are also following the global trends and becoming lighter and fuel efficient due to adoption of new materials such as composites, jute, carbon fiber, steel, aluminum, titanium, magnesium and plastics. Vehicle components are being manufactured with new materials and they are improving the aesthetics of vehicles. Examples

<table>
<thead>
<tr>
<th>Name of Technology</th>
<th>Description</th>
<th>Investment Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>Can be used for engine components like cylinder block</td>
<td>Investment required for indigenous development.</td>
</tr>
<tr>
<td>High Strength Steel</td>
<td>Used for all powertrain components like crankshafts</td>
<td>Investment required for indigenous development.</td>
</tr>
<tr>
<td>Magnesium</td>
<td>Can be used for steering wheels</td>
<td>Investment required for indigenous development.</td>
</tr>
<tr>
<td>Carbon Fibers</td>
<td>Can be used for vehicle interiors</td>
<td>Technology can be imported</td>
</tr>
<tr>
<td>Plastics</td>
<td>Can be used for fuel tanks and bumpers</td>
<td>Investment required for indigenous development</td>
</tr>
<tr>
<td>Composites</td>
<td>Can be used for fuel cylinders and some hot engine components.</td>
<td>Technology can be imported</td>
</tr>
<tr>
<td>Natural Fibers</td>
<td>Jute or coconut coir can be used as seat covers, floor mats etc.</td>
<td>Nil</td>
</tr>
<tr>
<td>Ceramics</td>
<td>Used for heat resistance and insulation.</td>
<td>Investment required for indigenous development</td>
</tr>
<tr>
<td>Nano materials</td>
<td>Used for coating of engine components.</td>
<td>Technology can be imported</td>
</tr>
</tbody>
</table>
are, bumpers made from plastic and synthetic fuel tanks and liner made from jute.

Automotive manufacturers and their suppliers must innovate in all areas of vehicle design in order to maximize fuel efficiency to meet fuel efficiency guidelines. To realize this goal, automakers are working to innovate new light-weight materials and integrate them into vehicle designs. Table 6.1 lists some new material technologies which have great potential in future.

### 6.5 RECYCLING ISSUES

Although end-of-life vehicle (ELV) recycling has been carried out for many years in developed countries, the new technologies and equipment are still under development in India. At the same time, the vehicle population of developing countries like India is increasing rapidly. The treatment of components after ELV and its recycling becomes a serious social problem. As the ground realities of India are different from the developed countries, the technologies and the equipment used by the developed countries cannot be simply imported to India in their present form. After analysing the structure of vehicle body, the scheme of flexible dismantling can be opted. It comprises of window shield cutting, pillar cutting and roof dismantling. By combining work cells and conveyer lines, a product line based dismantling mode for ELV recycling can be implemented. By this method, the energy consumed during the ELV recycling can be decreased immensely. Figure 6.2 provides the vehicle life cycle from recycling point of view.

### 6.6 CURRENT AND FUTURE RECYCLABILITY TRENDS IN GLOBAL ROAD TRANSPORT

Automakers are continually looking for creative ways to reduce waste and increase recycling opportunities in the entire process of manufacturing vehicles, starting from design stage to facilities management. Auto dismantlers remove reusable parts from vehicles for reuse.
on other vehicles. Examples of reusable parts include engines, transmissions, doors and bumpers. Parts that can be remanufactured or rebuilt are also removed, including alternators, water pumps, and clutches. Rebuilt parts are disassembled and cleaned, and components are replaced if necessary. For more than seventy-five years, automotive recyclers have been providing employment, consumer service and environmental conservation worldwide. In USA, the automotive recycling industry is a vital market-driven industry. In fact, automotive recycling is the 16th largest industry in USA, estimated to be a $25 billion per year. There are approximately 7,000 vehicle-recycling facilities in USA. Recycling the vehicles provides enough steel to produce ~1.3 million new vehicles, and generates jobs for 46,000 people in USA alone.

Material recycling is in a state of rapid change. In developed countries, transition from landfill disposal to energy and material recovery is already in full-swing, and the future trend is towards more efficient material, recovery and recycling processes. Recycling and reuse of automotive components will be economically attractive for public and private actors; energy recovery is limited to non-recyclable materials. Realization of these targets requires extensive development at both a technological and system level. One of the biggest challenges is the growing complexity of the products and related waste flows, which make recycling even more complicated. Figure 6.3 shows the schematic of the material recycling flow chart and processes.

Waste management market in developing countries is also growing rapidly, and at least some countries have the possibility and desire to introduce advanced technologies. Radical changes in the business environment offer great opportunity for companies, which are able to be in the forefront of the development of new technologies and services adapted to the
demands of a changing business environment. Material recycling technologies in the future will follow the waste recycling pyramid shown in figure 6.3, the focus being on reuse and ultimately reduction in material consumption in the first place.

6.7 INDIAN VEHICLE RECYCLING TRENDS AND GAPS
India is at the forefront of recycling and automotive recycling the need of the hour for its the developing economy. Auto dismantlers remove reusable parts from vehicles for reuse on other vehicles. Examples of reusable parts include engines, transmissions, doors and bumpers. Research Facility for vehicle recycling has been setup in Chennai under the NATRIP program. In the absence of ‘end of life’ norms for vehicles in India, very few old vehicles are scrapped as of now and therefore auto recycling is yet to pick up here.

6.8 GAPS IN RECYCLING SCENARIO
Currently there are no de-manufacturing facilities for vehicles in India. End of vehicle life norms are also required to be introduced to remove old vehicles from the streets. Facilities for de-manufacture of vehicles can separate recyclable and non-recyclable components. Recycling of auto components need to be taken on priority. Sufficient facilities for shredding old automobiles need to be created. Infrastructure for disposal of hazardous components like batteries needs to be created. Handling and disposal of auto shredded residues is another challenge.

REFERENCES

This section primarily covers the upcoming technologies and research areas along with some out of box research ideas or specifically blue sky research.

7.1 SMART FUTURISTIC TRANSPORTATION SYSTEM

Future transportation system must be “smart” so that it is able to not only react quickly to the demands placed on it, but also anticipate the demand in advance. The improved, smarter transportation system, which is envisioned, addresses these challenges to make the transport efficient, reliable, safe, and eco-conscious. Since transportation is an integral part of our economic well-being, as well as our modern day lives, the 21st century transport system has to be a tool for generation of wealth. The new system requires a committed effort with large investments and time, devoted for the return on investment to be positive. To guide this vision, it is required to create a roadmap for better, more intelligent and “smarter” transportation eco-system for future. This new system should address four main challenges that are emerging from the current system (figure 7.1) and for achieving these objectives, blue-sky ambitious research should be undertaken and government of India should invest heavily in blue sky research in order to make the country self-reliant in vital technologies domain.

**FIG 7.1 MAIN CHARACTERISTICS OF FUTURISTIC SMART TRANSPORTATION SYSTEM [1]**
7.1 FUEL EFFICIENT VEHICLES
For road transport sector, vehicle design is the most critical area of R & D because it affects all other issues related to vehicular emissions, passenger safety, transport economics etc. For efficient road transportation, all vehicles starting from a bicycle to heavy-duty trucks must be designed to deliver optimized performance and emissions from the power plant of that size.

Today, exhaustive modifications have been made in the engine technology such as introduction of MPFI system, CRDI system, and high pressure direct fuel injection systems. Now the focus has shifted from the engine to understanding the combustion phenomenon. Therefore research is being carried out full throttle to improve the combustion inside the engine and its control, in order to improve the fuel economy and emission reduction. Advanced combustion diagnostic techniques are also required for attaining these objectives. Advanced combustion concepts such as Homogeneous Charge Compression Ignition (HCCI) and Partially Premixed Charge Compression Ignition (PCCI) may solve some of the critical issues related to engine performance, emissions and durability, however they are still under development.

SOME OF THE BLUE SKY RESEARCH ASPECTS FOR VEHICLE SYSTEM DESIGN CAN BE

- Development of highly fuel efficient engines using newer combustion concepts such as HCCI, PCCI and GDI
- New thermodynamic cycles for engines with overall thermal efficiency > 70%
- Development of advanced after-treatment systems to reduce engine out emissions to background levels
- Intelligent powertrain and heating, ventilation and air conditioning (HVAC) management
- Super high efficiency electric machines and use of Superconductors
- Development of advanced electrical hybrid system to improve overall efficiency of vehicle
- Fully hydraulic hybrid drivetrain for utilization of deceleration energy
- Development of Super Light Car: The main objective is to develop an innovative multi-material lightweight design for vehicle structures [Fig 7.2]
FIG 7.2  STRUCTURE AND MATERIALS FOR SUPER-LIGHT CAR

- HIGH STRENGTH STEEL
- HOT-FORMED STEEL
- ALUMINIUM SHEET
- ALUMINIUM CAST
- ALUMINIUM EXTRUSION
- MG-SHEET
- MG-DIECAST
- FIBRE REINFORCED PLASTIC

WEIGHT REDUCTION: -30%

ADDITIONAL PART
COST: < 5.0 €/KG

HIGHLIGHTS:
- MG-STRUT TOWER (DIE CAST)
- MG-ROOF
- HOT FORMED STEEL DOOR APERTURE
- FR PLASTIC ROOF CROSS BEAM
- FR PLASTIC REAR FLOOR
- AI-CASTING REAR LONGITUDINAL
- POLYMER REINFORCED SEAT CROSS-MEMBER
Figure 7.3 describes the stages of developments for fuel and vehicle technology used in road transport sector. Gaseous fuels are already used as alternative fuels in current generation vehicles however sustainability of gaseous fuels is rather limited. Hence some advanced fuels and fuel processing technologies should be explored for the future. Some of the research ideas in this domain are:

(a) Integration of new bio-refineries with existing industrial complexes to reduce total capital costs and lower the cost of biofuel production. This optimal integration has to take into account different possibilities. Optimal integration of oil and biomass refining sections has to be enabled such that:
- The biochemical section uses hydrogen or low-grade heat from the oil refining section.
- The fractions produced in the biochemical section to be sent to the oil refining section, (figure 7.4).

Figure 7.4 shows an example of integrated bio-refining complex in which different segments of energy production such as fuel refining, biofuel
production have been combined to utilize the energy and co-products of one section into other one. This approach reduces the wastage of material and energy and optimizes the process.

(b) “Third-generation” and “Fourth-generation” biofuels will be the most advanced form of biofuels used in road transport sector. The fourth-generation biofuels will be either created using petroleum-like hydro-processing, advanced bio-chemistry, or revisionary processes like Joule’s “solar-to-fuel” method that defies any other category of biofuels.

(c) Advanced cars running with air as fuel.

(d) Energy bike/ cars: Automobile to run on water.

7.3 ROAD SAFETY

(a) Electronic Brake Force Distribution: Electronic Brake Distribution (EBD) is a braking system which adjusts braking according to the situation. It gives superior control and stability during an emergency. Unlike most braking systems, which distribute brake force through mechanical control, EBD applies brake force precisely through electronic controls. It recognizes that driving conditions braking situations and vehicle weight distributions are unique and constantly changing. The EBD control works with ABS, ensuring the most effective distribution of brake force between the brakes of the front and rear wheels.

- When braking around a corner, it also controls the brake force on the left and right wheels, helping maintain vehicle stability.
- Braking is now controlled electronically by the ABS Electronic Control Unit (ECU).

(b) Self driving and situationally aware vehicles (Figure 7.5).

(c) Collision avoidance and mitigation systems.

(d) Intelligent cruise control.

(e) Vehicle to vehicle communication system.

(f) Safe speed including speed alert.

(g) E-call: In case of accidents, the vehicle can even transmit a distress signal to the nearest emergency rescue center.

(h) Active safety devices in vehicles should take full account of pedestrians and cyclists.

(i) Rear-mounted radar.

(j) Night vision with pedestrian detection and automatic high-beam control.

(k) Vehicles can be automated using sensors and transmitted to avoid any kind of accident.

(l) Driverless car which can read the mind, follow area map for directions and drive to the desired destination (Figure 7.6).

(m) Vehicle Stability Control: VSC begins to
**FIG 7.5  SELF DRIVING AND SITUATIONALLY AWARE VEHICLE**

- **SENSES SLEEPINESS**
  A camera mounted on the steering column tracks the driver’s face for drowsiness or inattentiveness.

- **MEASURES SWEAT AND HEART RATE**
  Conductive pads measure heart-rate changes and palm temperature, infrared sensors monitor facial temperature.

- **MEASURES BRAIN WAVES**
  Wireless sensors embedded in the headrest could measure the brain’s electrical activity.

- **MONITORS HEART RATE**
  Electrodes embedded in the seat measure your heart beat.

- **SEND GLUCOSE-LEVEL ALERTS**
  A smartphone app can connect a Bluetooth-enabled glucose monitor to the car’s multimedia screen to warn if the driver is at risk of losing consciousness due to unsafe blood-sugar levels.
FIG 7.6 DRIVERLESS CAR
A schematic figure of driverless car is shown below which uses an array of sensors to navigate public roads without a human driver. Other components, not shown, include a GPS receiver and inertial motion sensor.

LIDAR
A rotating sensor on the roof scans more than 200 feet in all directions to generate a precise three-dimensional map of the car’s surroundings.

VIDEO CAMERA
A Camera mounted near the rear-view mirror detects traffic lights and helps the car’s onboard computers recognize moving obstacles like pedestrians and bicyclists.

RADAR
Four standard automotive radar sensors, three in front and one in the rear, help determine the positions of distant objects.

POSITION ESTIMATOR
A sensor mounted on the left rear wheel measures small movements made by the car and helps to accurately locate its position on the map.

over-steer or under-steer because of an emergency rolling avoidance measure, or by excessive speed in a corner; VSC will automatically activate. By adjusting the engine’s power output and braking each wheel independently, VSC helps to return the vehicle to a ‘zone of stable operation’.

Congestion raises the emissions from road transport. Basic agenda for blue sky research is:
(a) Rebuild intersections as roundabouts to improve safety and reduce delays.
(b) Fine tuned electronic toll collection (ETC) as well as road infrastructure charging may compensate for the shortcomings of more traditional schemes like fuel taxation.
(c) Automated roads as escalators to avoid traffic jams.
(d) Speed breakers consume lot of energy that can be avoided by using automatic sensors. Sensors installed in both road and vehicles automatically detect the low speed range and slow down cars.
(e) Vertical laning of road can resolve the problem of land requirement in future.

7.4 ROAD NETWORKS
While maintaining and reconstructing existing roads and bridges, improvements should cover complete streets (opportunities for bicycles and pedestrians), improve safety, increase efficiency, and minimize lifetime costs. An intelligent management of both travel demand and existing road traffic, according to environmental objectives is essential. Efficient and ubiquitous road charging infrastructure can help relieve congestion and contribute to reduced emissions per passenger or per ton goods transported.
7.5 TRAFFIC MANAGEMENT

Information transmitted to the vehicle about the circumstances pertaining to other components of the transport network, particularly the route on which the vehicle is moving, will enable the driver to assess options, during driving. It is also possible that some vehicle sensor systems might be used to assess some aspects of the road condition itself. A lot of primary accidents are caused by downstream traffic disturbances leading even to "secondary accidents" at the end of the congestion queue generated by the primary accident. The number of primary and secondary accidents could be considerably reduced by making the vehicles react more intelligently to these disturbances by warning the drivers about the dangerous situations or even reacting automatically to avoid or reduce the impact of an impending collision.

Reducing headways between vehicles without jeopardizing traffic safety has the potential to increase traffic capacity. Therefore, a dedicated ITS tool would be welcome in order to secure a practice, which is already prevalent in the field. The blue sky agenda for traffic management is as follows:

(a) Seamless real-time travel and traffic information, including multi-modal journey planning and information system.

(b) Freight information systems combining operators freight-flow and public traffic flow requirements contributing to the optimum use of road capacity and the reduction of negative impact on the environment.

(c) E-Call leading to a reduction in fatalities.

(d) Electronic Toll Collection as a key instrument for internalization of costs.

(e) Integration of several core applications for open in-vehicle telemetric platform.

(f) System to forecast about traffic jams and send it to drivers who are travelling in that direction.

(g) Development and implementation of congestion reduction devices.

REFERENCES


India has one of the most dense road networks in the world, with a total road length spanning more than 3.3 million kilometre. Traffic volumes have been steadily increasing over recent years. This has led to congestion problems in major towns and cities across the country. To avoid all these problems, a serious research and management effort is required in the field of traffic management systems, vehicle design and passenger safety. Existing system requires a large number of changes to improve the current scenario of road transport sector. Road transport sector requires a large number of advanced techniques for development of roads, in which some of them should be imported from external sources. Traffic management is the weakest part of Indian road sector and requires a set of tight rules and regulation. For automobile industry, existing system needs to update with advanced combustion concepts, which deliver higher efficiency and cleaner combustion. Energy efficient and cleaner systems like electrical vehicle, fuel cell based vehicles etc. need to be developed and adopted.

8.1 GLOBAL OBJECTIVES OF STRATEGY DEVELOPMENT FOR ROAD TRANSPORT

The road transport vision plan provides a guideline for future road network improvements and improvements in modes of transport. Main objectives of this strategic development plan can be grouped into following different categories such as:

- Economic objectives include reduction in delays, improvement in journey time, reliability mainly for business and commercial applications, and improvement in accessibility between critical locations.
- Social objectives include safety aspects, improvement in travel comfort, and reduction in adverse impacts of traffic for all

Two radical views for future road transportation are:

The first is a future, in which, technology totally transforms travel. In this, communities and work places are clustered ‘optimally’ with high efficiency systems for communications and activities, where they are spaced geographically to minimize the demand for physical movement. Such movement is efficiently priced in economic terms; where it takes place by means of a complementary set of high tech and low energy systems incorporating road, rail, urban under-ground and over-ground shared systems (public transport). Movement is coordinated by demand responsive real-time systems. Such a future would incorporate social inclusion as an integral part of its provision as well as pricing. The harmful impact on the environment would also be minimized.

The second radical future is a future, whose supply side is quite simply the same as that of today for all intents and purposes, with little changes in the types of roads or modes of transport or operating systems, beyond a limited continuation of the normal (i.e. historic) pattern of development. This is seen as radical because of lack of change at a fundamental level, rather than inspite of it. It is radical because it goes against common expectations.
sections of society in an inclusive manner.

- Government and regional planning policies are also important along with various constraints such as environmental, physical, and financial constraints. Government’s ‘Smart city’ policies and the related targets in the strategy objectives also aim at reducing transport related GHG emissions.

- Environmental objectives which are required to minimize impact on critical sites as environmentally sensitive and historic areas, as committed by India in COP-21 and subsequently rectified on 2nd October, 2016.

8.2 STRATEGIC APPROACHES FOR ROAD TRANSPORT SECTOR

Strategic planning for India’s transport sector is essential. The growth and development of Indian economy and society throughout the timeframe is covered in this ‘Technology Vision 2035’ document for India’s transport sector. For homogeneous and inclusive development of road transport sector, it is necessary to implement uniform development strategy, especially keeping in mind, weaker and underprivileged sections of the society. To follow these development objectives, implementation strategy is divided in seven categories based on implementation strategy, missions plans and responsible organization/s. These seven categories are: vehicle technology development; material and fabrication technology development; road network improvement; traffic management and safety; sustainable road transport; energy and environmental issues; and logistics.

8.2.1 Implementation strategy in vehicle technology development

Automotive technology is the key part of the road transport sector because it affects overall performance and effectiveness of the road transport. Efficient vehicles make road transport economical and lower emissions from vehicles are highly desirable for cleaner environment. To achieve these two key objectives, automotive engines either use fossil fuels or alternate fuels using conventional and newer propulsion technologies, as shown in the road map given in figure 8.1.

Although IC engines have been used for more than a century, significant improvements in energy efficiency and emissions reduction are still required. Enhancement of engine efficiency is one of the most promising and cost-effective approaches to increase vehicle fuel economy over next 20 years. Strategies for achieving higher engine efficiency targets for the complementary technologies should be developed, involving collaborative partnerships amongst vehicle and engine manufacturers, suppliers, national laboratories and universities.

The main objectives of such consortiums should be to:

1. Improve fuel economy of SI engines by more than 25% using advanced technologies such as downsizing, variable compression ratio, and lean-burn engines
2. Develop efficient combustion approaches for diesel combustion having near-zero emissions without complicated and expensive after-treatment devices
3. Develop technologies for energy recovery from engine’s exhaust using thermoelectric devices which convert heat to electricity, and can power vehicle and/or its auxiliary devices
TECHNOLOGY VISION 2035

ROADMAP FOR ALTERNATIVE PROPULSION SYSTEMS AND FUELS [1]

- ELECTRIC VEHICLE
  - i-REAL Motorcycle
  - ELECTRICITY
  - ROUTE BUS
  - PHV
  - FCV (BUS)
  - FCV
  - HV
  - DELIVERY TRUCK
  - HD TRUCK

- HYBRID VEHICLE & PLUG-IN HYBRID VEHICLE
  - PASSENGER CAR
  - SHORT COMUTER
  - DELIVERY CAR

- FUEL CELL VEHICLE
  - FUEL CELL VEHICLE
  - OIL/BIO-FUEL/CNG/SYNTHETIC FUEL ETC.
  - HYDROGEN
Several mission plans for this can be undertaken. These mission plans are discussed one by one to attain the set objectives in road transport sector by 2035.

MISSION PLAN I
-----------------
DEVELOPMENT OF ADVANCED COMBUSTION TECHNOLOGIES
(a) Research on existing advanced combustion technology as HCCI, PCCI, GDI etc.
(b) Foster collaboration amongst research organization, academia and automotive manufacturers for common, predefined and quantifiable goals.
(c) Availability of research funds to research and academic institutes for exploration of advanced combustion technology for future to make Indian technologically self-reliant in this domain.
(d) Academia and Research institutes should focus on new technology development rather than pure adaptation of existing technology. They should be encouraged to take risky technology challenges.
(e) Elimination of inefficient conventional and older combustion technologies, which reduce the effectiveness of the entire road transport sector.
(f) Foster research collaboration with reputed foreign research organization and automotive industries to co-development of newer automotive technologies.
(g) Strict implementation of emission control devices in newer vehicles to mitigate environmental issues caused by them.
(h) Implementation of safety components such as ABS, ESC, air-bags, anti-collision sensors etc. in modern vehicles for safer journeys.

RESPONSIBLE AGENCIES
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MISSION PLAN II
-----------------
MODIFICATIONS IN EXISTING ENGINE TECHNOLOGIES
(a) SWOT analysis of current engine technology and modifications based on issues in the current engine technology.
(b) New rules and regulations for strict
implementation of modifications in existing vehicles.

(c) Enhanced enforcement and control through more advanced inspection, testing and checking of systems and equipment, including improved information technology.

(d) Cost effective solutions for running vehicles to achieve overall improvement in current road transportation.

(e) Strict license policy for aged heavy duty vehicles.

MISSION PLAN III
------------------
DEVELOPMENT OF ALTERNATIVE FUEL TECHNOLOGIES

(a) Exploration of alternative source of energy such as gaseous fuels, 1st generation biofuels (alcohols, straight vegetable oils etc.), 2nd generation biofuels (biodiesel from non-edible oils) and 3rd generation (algae based) biofuels, biomass-to-liquid (BTL) fuels, bio-refineries, etc.

(b) Appropriate changes in vehicle components and system design for adopting these alternative energy sources.

(c) Research on performance and sustainability analysis of available alternative energy sources.

(d) National policy to support research and innovation, particularly to improve production processes and to lower costs.

(e) Encourage use of biofuels in public and private fleets.

(f) Regular public awareness programs to highlight the advantages of biofuels.

(g) Modifications in the distribution policy of fossil fuels to include alternative fuels.

(h) Cultivators and farmers should be encouraged to undertake plantations to provide the feedstock for bio-diesel and bio-ethanol production.

(i) Discount on parking charges and toll tax for alternative fuelled vehicles.

(j) Advanced number plates with green logo for alternative fuelled vehicles.

RESPONSIBLE AGENCIES
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MISSION PLAN IV
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DEVELOPMENT OF ADVANCED ELECTRIC VEHICLES
(a) Development of national strategy for electric vehicles.
(b) Rationalize the responsibility of R&D amongst various national laboratories, research institutes and automotive manufacturers.
(c) Development and implementation of prototypes and their advertisement for public awareness and education.
(d) Cost effectiveness and availability of electric vehicle for each section of the society.
(e) Functional collaboration with leading foreign automotive entities for concept generation.
(f) Evolve policy, regulations and standards for electric vehicles.
(g) Develop Recharging infrastructure, and associated guidelines.

RESPONSIBLE AGENCIES
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MISSION PLAN V
------------------
DEVELOPMENT OF FUEL CELL VEHICLES
(a) Initial research for feasibility analysis for India.
(b) Research for small scale fuel cell vehicle prototype development.
(c) Model analysis for hydrogen storage and supply.
(d) Financial support for research in fuel cell technology and human resource development.
(e) Technology adaptation from external sources to leap frog in this domain.
(f) Implementation of research results in vehicle prototyping for testing by OEMs.

RESPONSIBLE AGENCIES
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8.2.2 Strategy Implementation in Material and Fabrication Technology Development

Development of low cost, high strength, natural and recyclable materials is need of the hour for the Indian automotive industry. Both metallic and non-metallic materials have a significant role to play in terms of vehicle weight reduction and improving fuel economy. Important mission plans for appropriate material development for the automotive sector are:

MISSION PLAN I
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Development of high strength steel to replace conventional steel. This can reduce up to 30% vehicle weight in components. Similarly, use of high strength steel in total body structure can further reduce up to 15% vehicle weight.

MISSION PLAN II
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Steel and cast iron structural parts can be replaced by aluminum structural parts and components to achieve vehicle weight reduction up to 40 to 60%.

MISSION PLAN III
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Development of carbon fibre reinforced polymer (FRP), which can reduce vehicle weight by 50%.

MISSION PLAN IV
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Structural integrity and weight savings can be further achieved by application of novel materials such as polymer, metal foams, synthetic materials, tailored structures and adhesives.

MISSION PLAN V
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Vehicle energy consumption can be significantly reduced by glazing. Generally, glazing incorporates about 5% of the weight of a vehicle; however, lightweight glazing alternatives can reduce 50% of vehicle mass compared to conventional materials.

RESPONSIBLE AGENCIES
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Leading automotive manufacturers, Reputed Academic Institutes involved in materials research, Ministry of Commerce and Industry, National Research Institutes, Reputed Academic Institutes involved in material research, Leading industries related to material development, Ministry of heavy metals, Ministry of Steel, Ministry of Science and Technology.
8.2.3 IMPLEMENTATION STRATEGY IN ROAD NETWORK IMPROVEMENT

MISSION PLAN I
--------------
PROPERLY CONSTRUCTED AND MAINTAINED ROAD INFRASTRUCTURE
(a) Road transport infrastructure should be improved and rationalized.
(b) Implementation of Road Sector Master Plan (RSMP) for all new and existing roads.
(c) Develop and implement national programs for routine and periodic road maintenance.
(d) Implement National Road Services Improvement Program (NRSIP) using advanced techniques for road construction and maintenance.

MISSION PLAN II
--------------
EMPOWERING THE ROAD AUTHORITIES TO DEVELOP AND PERIODICALLY MAINTAIN ROAD NETWORK
(a) Create a single road authority at national level for decision making and financial control.
(b) Authority to regulate, license and monitor activities in road networks.

MISSION PLAN III
--------------
ENCOURAGE INVOLVEMENT OF PRIVATE SECTOR IN CONSTRUCTION AND MAINTENANCE OF THE ROAD NETWORK
(a) Develop a suitable legal framework for private sector participation, including roles and responsibilities along with rights.
(b) Develop and publish regulations regarding tariffs, investment criteria and bidding procedures.

MISSION PLAN IV
--------------
ENCOURAGE PRIVATE SECTOR PROVISION OF ROAD TRANSPORT SERVICES.
(a) Development of vehicle fitness testing stations.
(b) On-street parking management.

(c) Construction and operation of off-street parking facilities.

(d) Improvement in urban bus services and taxi operations.

(e) Strict implementation of road safety rules and regulation.

(f) Traffic management measures.

(g) Reduce regulatory barriers to promote private sector participation.

MISSION PLAN V
---------------
DEVELOPMENT OF POLICY, REGULATIONS AND INSTITUTIONAL FRAMEWORK FOR TRANSPORT SECTOR

(a) Develop transport policy and properly align it with other important policies such as Energy Policy, and motor vehicle policy.

(b) Transport policy should be flexible to ensure equality of opportunity and accountability

(c) Update motor vehicle policy.

(d) Rationalize vehicle licensing and registration system.

(e) Public education and awareness drive for transport-related legislations.

RESPONSIBLE AGENCIES
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8.2.4 IMPLEMENTATION STRATEGY IN TRAFFIC MANAGEMENT AND SAFETY

MISSION PLAN I
--------------
DEVELOP DRIVER FEEDBACK SYSTEM/ INTELLIGENT ROADS

(a) Implement real time broadcast of traffic data and routing congestion alleviation

(b) Provide advanced systems for guidance/instructions to the road users

(c) Development of traffic control devices rulebook and its periodic update

(d) Publish, distribute drivers and instructors manuals and its periodic update
MISSION PLAN II
------------------
DEVELOPMENT OF SPECIFIC PUBLIC TRANSPORT SYSTEM FOR STUDENTS
(a) Scheduling of public transport to provide adequate capacity and coverage at peak travelling times for students
(b) Consider transportation issues and needs in the development of the education system

MISSION PLAN III
------------------
IMPROVE ROAD SAFETY STANDARDS FOR MOTOR VEHICLES
(a) Regulate vehicle weights to ensure better road condition and more efficient freight vehicles
(b) Regulate the licensing of modified vehicles
(c) Certify and license motor vehicle garages
(d) Strengthen accident investigation units
(e) Improve the operations of vehicle fitness testing stations

MISSION PLAN IV
------------------
IMPROVE FLOW OF TRAFFIC IN URBAN CENTRES
(a) Development of new traffic management plans for major urban areas and strict implementation of traffic rules
(b) Specific traffic management measures in critical areas to reduce traffic congestion including intersection redesign, one-way traffic systems etc.
(c) Arrangement of on-street parking management system
(d) Encourage construction and operation of off-street parking facilities wherever appropriate

MISSION PLAN V
------------------
REGULATE TAXI INDUSTRY TO ENSURE SAFE AND EFFECTIVE SERVICE
(a) Design of suitable authority to ensure vehicle fitness and driver capability
(b) Expansion of taxi routes where public bus system cannot fulfil the demand or the roads are too narrow for larger buses

RESPONSIBLE AGENCIES
----------------------
Reputed Academic Institutes involved in transport management research and ICT, Ministry of Road Transport and Highways, NITI Aayog, Ministry of Urban Development, Ministry of Rural Development, State Governments, National Highway Authority of India, State PWDs, Bureau of Indian Standards (BIS), Traffic Departments.
(c) Ensure proper infrastructure and supporting facilities and equipment for the public transport system

(e) Develop, maintain and operate terminals and transport centres

8.2.5 IMPLEMENTATION STRATEGY FOR SUSTAINABLE ROAD TRANSPORT

MISSION PLAN I
-------------------
PUBLIC BUS SYSTEM TO MEET SUSTAINABLE TRANSPORT REQUIREMENTS
(a) Restructuring of fare for public bus service based on cost of operation.

(b) Effective utilization of public transport by using suitable bus size depending upon route load.

(c) Easy access of public transport system for all vulnerable groups as students, elderly and persons with disabilities, women etc.

(d) Suitable arrangement for safe conditions on public transport vehicles.

(e) Standardize ticketing on all public transport vehicles.

(f) Reduced fare on public transport for all vulnerable groups including students, elderly and persons with disabilities, women etc.

MISSION PLAN II
-------------------
SUSTAINABLE MEANS OF FUNDING ROAD MAINTENANCE BY APPLYING "USER-PAYS" PRINCIPLE
(a) Establish dedicated tax on fuel and increased license fee for heavy vehicles.

(b) Increase dedicated sources of funding for the Road Maintenance Fund.

(c) Increase and enforce penalties on overweight vehicles.

(d) Increase resilience of road network to hazards.

(e) Produce and implement a formal hazard mitigation strategy and a disaster management contingency plan for the road transport sector.

(f) Design, build and retrofit road infrastructure to meet current and projected hazard events.
MISSION PLAN III
------------------
PROMOTE USE OF PUBLIC TRANSPORT OVER PRIVATE CAR TRAVEL
(a) Develop and implement public education and sensitization programs to advertise the benefits of public transport.
(b) Increase attractiveness, comfort and efficiency of public transport system.
(c) Provide secure park and ride facilities.
(d) Improve perception and marketing of public transport.

MISSION PLAN IV
------------------
ENCOURAGE NON-MOTORIZED ROAD TRANSPORT SYSTEM
(a) Development of infrastructure to facilitate safe non-motorized transport such as bicycles.
(b) Design road infrastructure with adequate sidewalks and other safety features for pedestrians.
(c) Repair of all sidewalks with necessary facilities.
(d) Ensure education and training, good traffic management techniques and better enforcement for non-motorized transport.

8.2.6 IMPLEMENTATION STRATEGY IN ENERGY AND ENVIRONMENTAL ISSUES

MISSION PLAN I
------------------
ENCOURAGE GREATER ENERGY EFFICIENCY AND LOWER ENERGY COSTS IN THE TRANSPORT SECTOR
(a) Promote fuel-efficient vehicles in the transport sector.
(b) Establish relatively higher tax on fossil fuels to encourage their conservation.
(c) Promote car-pooling opportunities e.g. preferential tolls, high occupancy vehicle (HOV) lanes.
(d) Encourage use of clean and energy efficient transport modes as pedestrian and bicycle modes

MISSION PLAN II
------------------
ENVIRONMENTALLY SUSTAINABLE TRANSPORT

RESPONSIBLE AGENCIES
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Reputed Academic Institutes involved in transport management research and ICT, Ministry of Road Transport and Highways, NITI Aayog, Ministry of Urban Development, Ministry of Rural Development, State Governments, National Highway Authority of India, State PWDs, Bureau of Indian Standards, Traffic Departments, Various local organizations related to road transport, Driving and automotive Training institutes.
INFRASTRUCTURE AND SERVICES
(a) Develop a land transportation system which is environment friendly.
(b) Ensure that road development is in compliance with government’s statutory regulations.
(c) Develop appropriate tax and pricing structure for road users to reflect environmental costs and other externalities.
(d) Strengthen facilities for testing of motor vehicle emissions to meet stipulated standards.

MISSION PLAN III
------------------------
STRENGTHEN RESILIENCE OF TRANSPORT SECTOR TO HAZARDS AND CLIMATE CHANGE
(a) Strengthen resilience of transport sector to natural and manmade hazards.
(b) Incorporate climate change adaptation and mitigation considerations in the design and construction of transport infrastructure.

8.2.7 IMPLEMENTATION STRATEGY IN LOGISTICS

MISSION PLAN I
---------------------
DEVELOP AND IMPLEMENT LONG-TERM PLAN FOR PUBLIC TRANSPORT SYSTEM INTEGRATED MULTI-MODAL OPTIONS FOR DIFFERENT MODES OF ROAD TRANSPORT.
(a) Long-term plan for public transport system is required for schools, private and government organizations and key critical areas.
(b) Periodic survey should be planned to determine population counts and passenger movement trends.
(c) Sustainable funding mechanisms for public transport system.
(d) To be able to accommodate the rate of urbanization, a rural township transportation model should be developed.

MISSION PLAN II
---------------------
DEVELOPMENT OF MULTI-MODAL TRAFFIC OPTIONS
(a) Availability of transfer facilities and routing rationalization according to suitable transport mode.

RESPONSIBLE AGENCIES
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(b) Roads should accommodate multiple modes of transport to reduce the total cost of travel.

MISSION PLAN III
-------------------
DEVELOP SAFE AND EFFICIENT MULTI-MODAL TRANSPORT FOR LOGISTICS HUB
(a) Integration of road and rail construction and its maintenance.
(b) Development of better rail and road connectivity between sea ports, airports and logistics centres.
(c) Integrate planning of telecommunications, energy, electricity and water infrastructure with road and rail corridors.

MISSION PLAN IV
-------------------
INTEGRATION OF TRANSPORT PLANNING INTO SUSTAINABLE REGIONAL, URBAN AND RURAL PLANNING.
(a) Integrate transport and urban and regional planning for parking, inter-transit transfer and pedestrian.
(b) Use of smart growth principles in urban and transportation planning.
(c) Integrate development of shipping channels and turning basins with environmental and spatial planning and coastal zone management.
(d) Environmental impact assessment studies should be undertaken for all new infrastructure projects.
(e) Involvement of stakeholder and consultations in planning and development of MMTS.

RESPONSIBLE AGENCIES
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Ministry of Road Transport and Highways, NITI Aayog, Ministry of Urban Development, Ministry of Rural Development, State Governments, National Highway Authority of India, State PWDs, Bureau of Indian Standards (BIS), Traffic Departments, Various local organizations related to road transport, Driving and automotive Training institutes, Ministry of Railways, Ministry of Shipping, Ministry of Civil Aviation, Ministry of Environment Forests and climate change.

REFERENCES
RAILWAYS
1.0 INTRODUCTION

Railways is one of the key modes of transport in achieving the targets set under the prerogative on ‘Safe and Speedy Mobility’ in the Technology Vision 2035 document, brought out by TIFAC, which was released on 3rd Jan, 2016 by Hon’ble PM Shri Narendra Modi in the 103rd Indian Science Congress at Mysore. It states that “no place will be more than three hours away from a district head quarters, five hours from the state capital and eight hours from the national capital.”

1.1 INDIAN RAILWAYS

Railways being one of the well structured, connected, fuel efficient and rapid transportation systems and also having less GHG emission potential, ranks first amongst the four modes of transport in India. Railways not only have the potential to generate high capacity with less land, it can also operate at relatively less cost. Hence, railways have turned out to be an attractive alternative to road transport. It acts as a catalyst to economic and social development. It consumes about 1/6th of the energy required for transport for carrying one tonne of freight traffic over a distance of one kilometre and 1/30th energy as compared to air transport. In case of passenger traffic, it consumes 1/50th to 1/15th of energy per car, depending upon the size of car[1].

First introduced in India in 1853, Indian Railways is the fourth largest railway network under single management. With the rail network of 66,030 km and a total of about 22,000 trains in operation which includes nearly 13,000 passenger trains and about 9,000 freight trains every day, Indian railways transports 3 million tonnes of freight traffic and 23 million passengers everyday[2]. It is noteworthy that since independence, India has added just 12,000 kilometres to its nationwide network. Train speeds haven’t increased much during this period. For instance, in the early 1950s, steam locomotive hauled trains had speed of 80-100 km/h, and today maximum commercial speed stands at 140 km/h, which is possible only in short stretches of track. Average speed of mail/express trains stand at 50.6 km/h and that of ordinary passenger trains at 36 km/h, whereas, average speed of goods train in broad gauge tracks remains at 25.9 km/h. Till now, just around 33% of the total Route Kilometres (RKM) only has been electrified.

Over the years, many countries have made remarkable progress in rail technology, enabling faster and safer movements. For instance, the Chinese rail system too was comparable with Indian Railways till the last decade, but has made a positive technological impact in the recent past. Indian Railways is poised to catch up with the lost time and aim at 2035.
### 1.2 KEY STATISTICS

The key statistics of Indian Railways as of 2014-15 is given in Table 1.1.

**TABLE 1.1: KEY STATISTICS AS OF 2014-15**

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<tbody>
<tr>
<td><strong>I</strong></td>
<td>ASSETS</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Route Length</td>
<td>KMs</td>
<td>64,460</td>
<td>64,600</td>
<td>65,436</td>
<td>65,808</td>
<td>66,030</td>
</tr>
<tr>
<td>2</td>
<td>Locomotives</td>
<td>Nos</td>
<td>9,213</td>
<td>9,549</td>
<td>9,956</td>
<td>9,956</td>
<td>10,773</td>
</tr>
<tr>
<td>3</td>
<td>Passenger Service Vehicles (Including EMU, DMU, DHMU)</td>
<td>Nos</td>
<td>53,220</td>
<td>55,339</td>
<td>57,256</td>
<td>59,589</td>
<td>61,558</td>
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<tr>
<td>4</td>
<td>Other Coaching Vehicles</td>
<td>Nos</td>
<td>6,500</td>
<td>6,560</td>
<td>6,614</td>
<td>6,791</td>
<td>7,000</td>
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<tr>
<td>5</td>
<td>Wagons</td>
<td>Nos</td>
<td>2,29,997</td>
<td>2,39,321</td>
<td>2,44,731</td>
<td>2,45,267</td>
<td>2,54,006</td>
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<td>6</td>
<td>Railway Stations</td>
<td>Nos</td>
<td>7,133</td>
<td>7,146</td>
<td>7,172</td>
<td>7,112</td>
<td>7,139</td>
</tr>
<tr>
<td><strong>II</strong></td>
<td>OPERATION</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Passenger: Train KMs</td>
<td>Million</td>
<td>655.4</td>
<td>681.5</td>
<td>703.8</td>
<td>734.1</td>
<td>759.0</td>
</tr>
<tr>
<td>2</td>
<td>Vehicle KMs</td>
<td>Million</td>
<td>19,666</td>
<td>20,819</td>
<td>22,309</td>
<td>23,542</td>
<td>24,802</td>
</tr>
<tr>
<td>3</td>
<td>Freight: Train KMs</td>
<td>Million</td>
<td>368.9</td>
<td>391.4</td>
<td>401.5</td>
<td>422.5</td>
<td>401.0</td>
</tr>
<tr>
<td>4</td>
<td>Wagon KMs</td>
<td>Million</td>
<td>17,749</td>
<td>19,139</td>
<td>19,855</td>
<td>19,546</td>
<td>18,930</td>
</tr>
<tr>
<td><strong>III</strong></td>
<td>VOLUME OF TRAFFIC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Passenger originating</td>
<td>Million</td>
<td>7,651</td>
<td>8,224</td>
<td>8,421</td>
<td>8,397</td>
<td>8,224</td>
</tr>
<tr>
<td>2</td>
<td>Passenger KMs</td>
<td>Million</td>
<td>9,78,508</td>
<td>10,46,522</td>
<td>10,98,103</td>
<td>10,51,64</td>
<td>11,47,190</td>
</tr>
<tr>
<td>3</td>
<td>Freight originating</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.1</td>
<td>Revenue earning traffic</td>
<td>Million tonnes</td>
<td>921.73</td>
<td>969.05</td>
<td>1008.09</td>
<td>1051.64</td>
<td>1095.26</td>
</tr>
<tr>
<td>3.2</td>
<td>Non-Revenue earning traffic</td>
<td>Million tonne km</td>
<td>6,25,723</td>
<td>6,67,607</td>
<td>6,91,658</td>
<td>6,65,810</td>
<td>6,81,696</td>
</tr>
<tr>
<td>3.3</td>
<td>Total traffic (incl. non-revenue)</td>
<td>Million tonne km</td>
<td>6,26,473</td>
<td>6,68,618</td>
<td>6,50,625</td>
<td>6,66,728</td>
<td>6,82,612</td>
</tr>
</tbody>
</table>
1.3 STRATEGY FOR TECHNOLOGY DEVELOPMENT

Various aspects needing attention, while evolving the strategy for rail technology development, especially in Indian context, include but not limited to:

(i) capacity to be created for the projected traffic (both passenger and freight),
(ii) transit times, which is directly related with operational speeds (maximum and average),
(iii) safety of operation,
(iv) security of passengers and goods,
(v) punctuality,
(vi) passenger comfort during travel and changeovers and
(vii) intermodal transit facilities.

1.4 TRAFFIC PROJECTION BY 2035 AND NEED FOR TECHNOLOGY INTERVENTION

Railway travel is very quite economical in India and normally passenger fares are kept much lower than other modes of transport, thus, making it a preferred mode for most of the low and middle-income groups in India. Being directly under the ministry and its working capital being made available from the consolidated fund of India, it follows an administered tariff.

Population rise is one of the important drivers for capacity addition in railways. By 2035, it is expected that population will increase up to about 1.53 billion from current (2015) figure of 1.25 billion. Hence capacity increase is a must for passenger traffic across all categories – medium-to-long haul, suburban and urban. This can be achieved only through additional capital investment and adoption of appropriate technologies. Unlike in many developed countries, Indian railways have a mixed traffic, running both passenger and freight trains on the same track. This type of operation drastically reduces the average section speed and throughput. The average section speed is directly related to the carrying capacity, be it passenger or freight.

This issue can be resolved in two ways – either by reducing the speed differential between passenger and freight trains, or by having dedicated passenger and freight lines. Having dedicated freight and passenger lines should be the ultimate aim.

Growth of traffic is measured using various parameters. Growth of traffic output and input since 1950 is given in Table 1.2[3].

Going by the past growth of freight traffic, since 1950-51 till 2010-11, the NTKM (Net Tonne Km) has grown on an average by 22% per year (100 units in 1950-51 to 1,420 units in 2010-11) and passenger KM has also grown by around 21.7% per year (100 units in 1950-51 to 1,403 units in 2010-11) on an average. By extrapolating the same trend, during the turn of 2035, the NTKM passenger traffic is expected to be around 2,000 units, which is an increase of almost 41% from the year 2010-11. Similarly, the passenger KM by 2035 would increase to 1,900 units, resulting in a growth of around 35% from the present level of 2010-11. But these extrapolations are linear based on the past record. By increasing the efficiency and customer friendliness, these figures can be much higher; by attracting traffic from the road and air sectors.

The growth indices are graphically illustrated in Figure 1.1. While both passenger and freight traffic have phenomenally increased since 1950, as could be seen from the steep curves, rest of the growth inputs involving capital investment have remained almost stationary. Most importantly, the running track km and route km have remained almost static. This also explains the reason for the present supply-demand crisis and the consequent huge customer dissatisfaction. This supply-demand gap can be addressed only through appropriate growth inputs and technology intervention, both need huge investments.

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<tbody>
<tr>
<td>4</td>
<td>Quantity of fuel consumed by locomotives</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>4.1</td>
<td>Diesel</td>
<td>l in kilo-litres</td>
<td>25,16,044</td>
<td>27,05,084</td>
<td>26,99,616</td>
<td>2789260</td>
<td>2856190</td>
</tr>
<tr>
<td>4.2</td>
<td>Electricity</td>
<td>l Million KWH</td>
<td>13,571.53</td>
<td>13,449.98</td>
<td>13,853.44</td>
<td>15169.16</td>
<td>15742.89</td>
</tr>
</tbody>
</table>
### TABLE 1.2: GROWTH OF TRAFFIC OUTPUT AND INPUTS (1950-51 = 100)

<table>
<thead>
<tr>
<th>Year</th>
<th>Traffic Output Indices</th>
<th>Investment Input Indices</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Freight Traffic (NTKMs) (Rev + Non Rev)</td>
<td>Passenger Traffic (Non-suburban passenger km)</td>
</tr>
<tr>
<td>1950-51</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>1960-61</td>
<td>199</td>
<td>110</td>
</tr>
<tr>
<td>1970-71</td>
<td>289</td>
<td>159</td>
</tr>
<tr>
<td>1980-81</td>
<td>359</td>
<td>279</td>
</tr>
<tr>
<td>1990-91</td>
<td>550</td>
<td>394</td>
</tr>
<tr>
<td>2000-01</td>
<td>715</td>
<td>614</td>
</tr>
<tr>
<td>2007-08</td>
<td>1185</td>
<td>1084</td>
</tr>
<tr>
<td>2008-09</td>
<td>1251</td>
<td>1189</td>
</tr>
<tr>
<td>2009-10</td>
<td>1363</td>
<td>1288</td>
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<tr>
<td>2010-11</td>
<td>1420</td>
<td>1403</td>
</tr>
<tr>
<td>2011-12</td>
<td>1516</td>
<td>1505</td>
</tr>
<tr>
<td>2012-13</td>
<td>1570</td>
<td>1588</td>
</tr>
</tbody>
</table>

### FIG 1.1: THE GROWTH INDICES

- **Freight Traffic (NTKMs) (Rev + Non Rev)**
- **Passenger Traffic (Non-suburban passenger km)**
- **Wagon Capacity**
- **Passenger Coaches**
- **Route kms**
- **Running Track KMs**
- **Tractive Effort of Locos**
2.0

INDIA vs. GLOBAL TRENDS – PRESENT AND FUTURE SCENARIO

There are various parameters which can be measured while comparing the Indian railways with other countries. However, the standard indicator is the length in km, which includes urban/suburban mass transport system.

According to the International Union of Railways (UIC), Indian railways to be counted as one of the best in the world, but still lags behind the developed countries (United States of America (USA), Germany, France and Japan) in terms of route-km per square km or route km per million populations served. United States has over 300,000 route km owned by nearly 215 agencies including all types of lines, all 1435 mm standard gauge. China has nearly 1,44,000 route km comprising 3 gauges of 1435 mm (predominant), 1520 mm (Russian gauge) and 1000 mm (metre gauge) whereas, Russia has 128,000 route km comprising 2 gauges of 1520 mm (predominant) and 1067 mm (cape gauge). India is at the 4th position with 66030 km of route length of predominantly broad gauge (1676 mm)[4].

In terms of originating freight per year, there are only four countries in the world that carry more than 1 billion tonnes of originating freight per year and these are – China, Russia, United States[5], and India. Various key global technology areas and trends are examined in this section, and compared with the current state of technology in India.

Rail transport is used widely in many countries. In Europe and Japan, electricity is a major energy source for rail, while diesel is a major source in North America. Coal is also still used in some developing countries. In India, it is dominated by diesel as major energy source for locomotives; however, just around 33% of IR route km has been electrified so far; on which around 66.5% of freight and 51% passenger traffic is hauled, the fuel cost on electric traction remaining just 31% of the total fuel cost[6].

The technology prowess of any railway system is often gauged by their high-speed operation. Japan was one of the pioneers of high speed technology with its (Shinkansen) bullet train, initially running at a commercial speed of about 230 km/h. This was subsequently raised to 300 km/h and 320 km/h, and recently its maglev bullet train has reached a speed of 603 Km/h. French National Railways (SNCF) high-speed train TGV (Train of Grande Vitesse) recorded a test speed of 574.80 km/h, on April 3, 2007. China, who started developments on high speed operation rather late, soon overtook all the players by operating the world’s fastest trains at 380 km/h. France, Germany, Italy, Japan, Korea and China are the countries in the elite high speed club. High speed is a relative term, and today in the global context, commercial speeds of above 300 km/h can be considered as a high-speed operation, though in Indian context, speeds above 200 km/h can be treated as high-speed. Fig 2.1 gives a country-wise comparison of the operation speeds (maximum speed in revenue service)[7].
Recently the Indian Railways reached the maximum operating speed of 160 km/h from the earlier maximum speed of 140 km/h. However; the average speed is 100 km/h, which is quite less due to mixed passenger and freight traffic on same tracks. Indian Railways is now contemplating adopting high-speed operation by making dedicated high-speed corridors. The speed of operation is expected to increase further up to 250-350 km/h.[8].

From the above, it is clear that Indian railways is far behind many developed railways, however, this can be overcome through expanding the capacities of the railways as well through the adaptation and development of new and advanced technologies.

2.1 HIGH SPEED PASSENGER OPERATION

According to UIC, “High speed rail is not only a technical subject, but encompasses a complex reality involving various technical aspects such as infrastructure, rolling stock and operations and cross-sector issues such as financial, commercial, managerial and training aspects.”[9]. In the Indian context, speeds of above 200 km/h can be considered under high speed operation, as it involves various special factors and procedures mentioned above.

In railways, the iron wheel translates the rotary motion into linear motion of the train through rail-wheel friction. Till early 1980s, it was believed that the maximum speed that could be achieved through rail-wheel friction is 200 to 250 km/h. In
order to break this barrier, development happened in the field of magnetic levitation, in which, the driving force of the train is not transmitted through friction, but through electro-magnetic force available through linear motors, and the train floats on guides while in motion. As the force and power requirements are quite large, needing huge currents, superconductivity is needed for reducing the losses. The pioneering work was done by Japan and experimental models with tests speeds of close to 500 km/h were achieved. However, due to exorbitant cost of track, rolling stock and associated technologies, maglev technology has not proliferated as a mode of rail transportation commercially. This could be the reason for many countries in Europe and also Japan, to do further research in the rail-wheel friction technology, which resulted in increasing the speeds beyond the earlier barriers and reaching 250, 300 and 350 km/h, and France (TGV) ultimately achieving the record test speed of 574.80 km/h in 2007.

In view of the above developments, in the Indian context, at least for the present and near future, rail-wheel friction technology would be the feasible solution for high speed commercial operation, though, this too is quite expensive. Use of lightweight materials, designs providing low aerodynamic drag, tracks with very low curvatures, use of onboard mechatronics to reduce the forces while train negotiates curves (like tilting technology, self steering bogies etc) in order to keep the passenger comfort and derailment coefficient within acceptable limits are some of the mandatory requirements for high speed trains.

2.1.1 Maglev
A detailed discussion on Maglev is not within the scope of this report; however, for the sake of basic appreciation, it is to be understood that Maglev trains essentially float on a cushion of air at very high speed; it moves between two electromagnetic fields, without physically touching the rail track and doesn’t use any fossil fuel to run. Since Maglev train does not carry engines and the equipments such as transformers, inverters and wheels thus make light weight and hence no adhesion or friction problems. In addition, superconducting magnets makes it capable of harnessing large propulsive power. Images of Maglev trains are given in Fig 2.2.

Maglev technology has received the most attention, particularly in North America, as a result of its ability to greatly reduce its environmental impact on surrounding communities. Germany and Japan are the pioneer nations in utilizing Maglev technology. Japan has developed the High Speed Surface Transport (HSST), while Germany has developed the Transrapid system. Recently, Japan has been promoting a newer version of the Maglev known as the superconducting Maglev technology[10].

2.1.2 Riding Comfort and Tilting Technology
The tilting technology has now become a requirement for high speed operation. When the train travels at high speed curved tracks, particularly on existing railroad tracks, the coach senses the curves and tilts itself suitably to nullify the effect of centrifugal force. The advantage of tilting trains is that they can negotiate curves faster than ordinary trains, thus reducing the level of discomfort that passengers normally experience otherwise. At the same time, this method reduces the track forces which in turn improves the vehicle stability at high speeds on curved tracks.

Switzerland and Great Britain are the latest among the European countries to introduce tilting train
technology. In 1996, Germany introduced its latest ICE2 (Inter City express-2) trains as tilting trains, which could travel at an average speed of 235 km/h. Some other countries that employ tilting trains are Sweden, Norway, Japan, Italy, Finland, Portugal, Slovenia, Australia and the USA.

2.1.3 Comparison of Magnetic Levitation with High speed trains employing rail-wheel friction technology

As discussed above, high speed operation is possible by adopting either Maglev technology or standard rail-wheel friction technology, the relative cost becoming the predominant deciding factor. Maglev guide paths are bound to be more costly than conventional steel railways (see Fig 2.4) and hence needed specific magnetic track infrastructure, which is the major challenge in the implementation of Maglev.

India needs to indigenously develop passenger carriages capable of safely operating at peak commercial speeds of 350 km/h and test speeds of above 400 km/h. This feat has been achieved by many countries earlier; the latest being China. This will entail development of various associated products and technologies which would include but not limited to:

(i) Capability of simulation and model studies
(ii) High speed test tracks of considerable length and ability to simulate various conditions.
(iii) Capability to design and simulate high speed bogies and test the prototypes in test tracks especially from the point of view of track forces, vibration and derailment coefficient.
(iv) Suspension technology for high speed, bringing in passenger comfort within acceptable levels.
(v) Technologies similar to tilting technology for increased passenger comfort and for reducing accidents.
(vi) Lighter and stronger composite materials similar to the one needed for aircrafts.
(vii) Acoustic design and noise reduction technologies.
(viii) Design to take care of crash and impact and test for crashworthiness.
(ix) Capability to design and develop aerodynamic designs.
(x) Brake systems suitable for high speed.
(xi) Inter-vehicular couplers (mechanical, pneumatic, power and signalling).
(xii) High reliability door closing mechanisms.
(xiii) Platform surveillance system.
(xiv) Illumination, heating, ventilation and air-conditioning systems with highest energy efficiency with a possibility to use solar power and/or regenerated power from the locomotive.
(xv) Fire retardant and fire resistant materials
(xvi) Environment friendly bio-toilets etc.

2.1.4 Locomotive Design

At high-speed operation, due to vintage, loss becoming more predominant, the power requirement of locomotive becomes enormous. Very high power locomotives need to be developed with most energy efficient propulsion systems. Currently, Indian Railways manufactures 4.5 MW locomotives. The propulsion system is 3-phase drive using asynchronous motors, employing either GTOs or IGBT technology. Most of the technologies used currently are adopted or adapted from European designs through technology transfer, license production or direct sale. In order to make it viable and maintainable, indigenous development is a must.

Even though developed countries like Europe, Japan and China also during the recent years, are operating railways at high speed, has made rapid strides in developing propulsion systems for both synchronous and asynchronous drives through a series of evolution using thyristor, GTOs and IGBTs. Such an event is yet to start in India. Going by the statistics of research papers in power electronics published in international forums like IEEE, Indians may top the list, but yet, the propulsion system development in India has not really happened. This is a very high value and critical component.
in motive power and needs to be developed indigenously. Very recently, an Indian Company has succeeded in developing IGBT based propulsion drives of 4.5MW capacity, which is being used in commercial operation. This is a silver lining, and creates confidence that capability exists in India. However commercialization of those advanced technologies can be possible through synergetic partnership between Academia, R&D institutes, Government as well as industry. India has the knowledge base and wherewithal to do it, only the right agencies are to be brought together and strategized. The technology that would be needed in the next two decades for entering into high speed operation (but not limited to) are as shown in fig 2.5.

**FIG 2.4: COMPARISON OF MAGLEV WITH HIGH SPEED TRAIN TECHNOLOGY[11].**
2.2 HEAVY AND LONG FREIGHT TRAIN OPERATIONS

Some of the methods used for higher throughput of freight in railways include:
- running longer and/or heavier trains,
- having dedicated freight corridors,
- increasing the average speed of freight trains, and
- improving wagon turn-round at terminals, etc.

Countries like Australia, USA, China and South Africa use heavy haul, by use of distributed power, for phenomenally increasing the throughput with minimal infrastructural inputs and modifications in the wagons. Distributed power operation amounts to attaching many trains one after the other and all controlled by a master locomotive having a single crew. The locomotives distributed across the trains, are controlled by the master through a radio link or a wired data connection. The long trains so formed are run under one signal path. Table 2.2 shows the maximum freight load carried by a single distributed power train in certain countries using this technology[12].

On the contrary, Indian Railways predominantly operate trains with 58-wagon length, having train load of around 5000 tonne. In the recent past, it has started operating two trains together to increase the load up to 118 wagons, by using voice controls between drivers of the two connected trains. Indian Railways aims to achieve heavy haul with 200 wagons train with 32,000 tonne load, to be run with Radio Remote Control Equipment being developed indigenously[13]. The technology gap is clearly visible from Table 2.2.
The axle load of a wheeled vehicle is the fraction of total vehicle weight resting on a given axle. Axle load is an important design consideration in the engineering of railways, as exceeding the maximum rated axle load will cause damage to the tracks. A given section of track is designed for a prescribed maximum axle load. The maximum axle load is related to the strength of the track, which is determined by weight of rails, density of sleepers and fixtures, train speeds, amount of ballast, and strength of bridges. Because track and especially the rails are expensive, it is desirable to optimise the track for a given axle load. If the track is overloaded by trains that are too heavy, it can be damaged in a short time.

Increasing the axle load means increasing the load carrying capacity of the wagons. At the same time, it further stresses the track. This demands enhanced design features, which adds to input cost. Hence, compromise is sought for an optimum axle load.

Many developed railways have adopted axle loads that are much higher than the axle load limits used in Indian railways. Increased axle load directly increases the throughput, as can be seen from Table 2.3[15]. For the same length of trains (58 wagons), the throughput increases considerably.

Table 2.4 shows the axle loads prevailing in some of the highly developed freight operating railways[16]. In contrast, Indian Railways operate at an axle load of 20.5 tonne. Efforts are being made now to increase the axle load to 22.9 tonne and later to 30 tonne in the dedicated freight corridor. Even after achieving this, there is still a gap when compared with countries like the USA and South Africa.
2.4 Payload to Tare Weight Ratio of Wagons

Tare is the weight of an empty wagon, whereas, payload is the actual useful material that can be carried in the wagon. Tare and payload adds to make gross loads. Once the maximum axle load for a particular railway is fixed, the gross weight also gets fixed. In order to have more productivity from a wagon, higher payload to tare ratio is needed. This is possible by reducing the tare weight, which can be achieved by using lighter wagons by way of using suitable materials for construction.

Indian Railways use many types of wagons, in which the ratio varies from 0.9 up to 2.6 (2.6 in case of BOXN type)\[17\]. The material used for construction is steel, which adds to the tare weight. Indian Railways have taken up development of lighter wagons to achieve payload to tare weight ratio of 3.4 by using stainless steel\[18\]. By using aluminium and other composites, it can be further improved.

In contrast, the payload to tare ratio prevalent in the US railroad and Western Railroads are in between 3.5 to 4.5\[19\]. While Indian Railways carry about 450 kg of dead weight for every 1,000 kg freight, the dead weight in the US does not exceed 170 kg. European Railways have already initiated an Innovative Rail Freight Wagon Design 2030 programme to develop state-of-the-art technology in freight carriers\[20\].

ECPB in wagons is a very effective way of improving the throughput of a train by way of fast braking and release times. This is similar to the pneumatic braking presently used in the Electrical Multiple Units. Indian Railways may like to pursue the ECPB technology.

2.5 Electronically Controlled Pneumatic Brakes (ECPB) in Wagons

Traditionally, brakes are applied from wagon to wagon along the train in a sequential manner. On a 150-wagon freight train, this could take up to two minutes between operation of the control valve on the leading locomotive and the application of brakes on the last wagon\[21\].

In contrast, ECP braking uses electronic controls, which make it possible to activate air-powered brakes on all the wagons throughout the train at the same time. Applying the brakes uniformly and instantaneously in this way gives better train control, shortens the stopping distance, and leads to a lower risk of derailment or of coupling breakage. The ECPB can also apply the brakes on the rearmost wagons, slightly before the brakes on the front wagons are applied, which reduces the shock and noise of the wagons bunching up.

The ECP brake control system consists of locomotive equipment, wagon braking equipment, an ECP End-of-Train device, and a power and communications distribution system. The locomotive equipment, referred to as the Head-End-Unit (HEU), consists of a train-line communications controller, train-line power supply and an identification module. The wagon equipment consists of the car control device, vent valve, wagon identification module and junction boxes. Train-line cable and connectors are provided on both the wagon and locomotive.

The South African Transnet Coal-line was the first major heavy-haul operator in the world to apply ECP/WDP (wired distributed power) brake technology as opposed to RDP (radio distributed power) to its entire fleet\[22\].

ECPB in wagons is a very effective way of improving the throughput of a train by way of fast braking and release times. This is similar to the pneumatic braking presently used in the Electrical Multiple Units. Indian Railways may like to pursue the ECPB technology.

2.6 Intelligent Adhesion Control System in Locomotives

In rail vehicles, the torque of the motorised rotating wheel is translated to linear force and transmitted to the locomotive through friction (normally known as adhesion) between the propelling wheel and the rail, and the maximum value is limited by the coefficient of adhesion, which is a physical phenomenon. Hence, even though the locomotive may be very powerful, it is not necessary that it can provide enough pull to the train, unless coefficient of adhesion is favourable.

On the other hand, coefficient of adhesion varies widely depending upon the track and environmental conditions. A dry rail offers a better adhesion, whereas, a wet and greasy rail offers low adhesion values. If the adhesion is poor but the locomotive generates more tractive effort, which cannot be sustained through friction, the remaining effort goes for accelerating the wheel, known as wheel slip. The coefficient of adhesion is the ratio of tractive effort at which the wheel slip occurs to the dead weight of the locomotive. The maximum force that can be transmitted to the trailing stock is $T = \mu W$, where $\mu$ is the coefficient of adhesion and $W$ is the deadweight of the locomotive.

Due to axle load considerations, the weight of the locomotive cannot be increased beyond a point. Hence, in order to derive maximum tractive force,
adhesion realised must be improved. For this purpose, an intelligent adhesion control system is needed, which monitors the wheel slip conditions and interacts continuously with locomotive propulsion control system and optimises the power to derive maximum adhesion at any given point of time. Some developed railways have implemented fuzzy algorithms and radar based sensing for achieving this.

Many modern locomotives presently used by Indian Railways have some level of adhesion control system, but there is room for further improvement.

2.7 SIGNALLING AND TRAFFIC MANAGEMENT SYSTEM
For safe and efficient running of trains at high speed and maintaining the scheduled time, signalling, communications and control play a vital role. Europe, in coordination with UIC – the International Union of Railways – was the pioneer in evolving a standard for signalling, train operation and control requirements, termed as ETCS (European Train Control System). It defines various standards and interfaces of track, rolling stock, signalling and communication equipment, which has to work in an integrated way. The ETCS has also evolved over the years and different levels have come over a period of time.

With the introduction of vehicle to wayside communication over a dedicated frequency band GSM-R, the entire system has been integrated and is known as ERTMS (European Traffic Management System), which essentially is a combination of ETCS Level 3 and GSM-R. The latest prevailing ETCS Level 3 is a radio based train control system (communication based train control). Europe leads in implementation of the ERTMS, while in Asia, China, Taiwan and South Korea lead in making new contracts for implementation[23]. Indian Railways are yet to implement, but only some subtle move has started.

ERTMS needs both trackside and on-board implementation and it tremendously improves throughput and enhances safety considerably.

2.8 PASSENGER COMFORT
For increasing the riding comfort, some developed railways use tilting technology for high-speed trains. The passenger carriages used in Indian Railways do not offer good riding comfort at high speeds and needs changes in design.

2.9 SPECIAL WAGONS
Present portfolio of wagons does not cover the requirement of all types of commodities transported at present. Such special wagons need to be developed.

2.9.1 Double Stacked Container
Container service, per se, is an intermodal transport, as it can be transported by road, rail, sea etc. Use of double stack containers in rail transport just doubles the carrying capacity. Indian railways should develop wagons suitable for carrying double stack containers. As a corollary to this, the tracks also need to be augmented for higher axle load of 30 tonne to 35 tonne.

2.9.2 Wagons for refrigerated goods
At present, Indian Railways have a fleet of 10 refrigerated parcel vans, which are attached to long distance mail/express trains as per demand. About 98 insulated-ventilated containers are running on Indian Railways as special trains as per demand. More Wagons suitable for carrying refrigerated goods need to be developed. This will enable transport of perishables from one part of the country to another part without any damage. Moreover, preferential transport of perishable goods is also required much attention.

2.10 BRIDGING THE GAP
Many of the challenges in future are expected to be tackled through appropriate technological inputs in various spheres. Before we really think about what we would do in the next 20 years, it is worth auditing the present Indian scenario with that of the developed world.

Even today, there is considerable gap between India and the ‘Best in the World’. In the next 20 years, it is quite natural that many new technologies will evolve which would change things that we see today. In order to catch up with this race, we literally have to leap forward. Railway technology is not so restricted unlike defence or space technology, and the same can be bought at a cost. A technology partnership with ‘Best in the World’ in each sphere of activity is possible. Indian Railways is moving in this direction and with Indian economy opening up, this is quite achievable. Indian industries could not come any closer to the leaders in the railway technology in developed countries, may it be high speed, propulsion system or signalling, and there are reasons as well, which may be answered in subsequent sections.
3.0
STATUS OF TECHNOLOGY AND AVAILABILITY OF RESOURCES

3.1 TECHNOLOGIES UNDER CONSIDERATION
The areas considered for discussion with regards to the status and availability of technology include:
(i) High Speed Operation,
(ii) Heavy Haul,
(iii) Signalling and Traffic Management System,
(iv) Safety-related,
(v) Security-related, and
(vi) Passenger Comfort-related.

3.1.1 Technologies related to High Speed Operation
High-speed operation will need development of many associated technologies, some of which are given in Table 3.1, along with availability of resources.

High-speed operation is a technology well proven in Europe and in countries like China and Japan. It involves development of a large number of associated technologies, which can be purchased from proven sources. However, they could be prohibitively costly and may not be sustainable.

### TABLE 3.1: HIGH SPEED TECHNOLOGIES

<table>
<thead>
<tr>
<th>SL No</th>
<th>Associated Technology</th>
<th>Availability of Resources Indigenously</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Capability of simulation and model studies</td>
<td>Will need outside consultancy</td>
</tr>
<tr>
<td>2</td>
<td>High speed test tracks of considerable length and ability to simulate various conditions</td>
<td>Design will need outside consultancy</td>
</tr>
<tr>
<td>3</td>
<td>Capability to design and simulate high speed bogies and test the prototypes in test tracks especially from the point of view of track forces, vibration and derailment coefficient</td>
<td>Will need outside consultancy</td>
</tr>
<tr>
<td>4</td>
<td>Suspension technology for high speed operation bringing in passenger comfort in acceptable levels</td>
<td>Will need outside support</td>
</tr>
<tr>
<td>5</td>
<td>Tilting technology (or similar technologies employing Mechatronics) for increased passenger comfort and reducing accidents</td>
<td>Will need outside support</td>
</tr>
<tr>
<td>6</td>
<td>Lighter and stronger composite materials similar to the one needed for aircrafts</td>
<td>Partially available. Can be fulfilled with technology tie-up between industries in India and abroad.</td>
</tr>
<tr>
<td>7</td>
<td>Acoustic design and noise reduction technologies</td>
<td>Will need outside support</td>
</tr>
<tr>
<td>8</td>
<td>Design to take care of crash and impact and test for crashworthiness</td>
<td>Will need outside consultancy</td>
</tr>
<tr>
<td>9</td>
<td>Capability to design and develop aerodynamic designs</td>
<td>May need outside consultancy. Can also be tried out indigenously.</td>
</tr>
<tr>
<td>10</td>
<td>Brake system suitable for high speed</td>
<td>Can be obtained/developed through the existing brake system suppliers like Knorr-Bremse, Faiveley, Wabco etc.</td>
</tr>
<tr>
<td>SL No</td>
<td>Associated Technology</td>
<td>Availability of Resources</td>
</tr>
<tr>
<td>-------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>---------------------------</td>
</tr>
<tr>
<td>11</td>
<td>Inter-vehicular couplers (mechanical, pneumatic, power and signalling)</td>
<td>Will need outside support</td>
</tr>
<tr>
<td>12</td>
<td>Door closing mechanisms</td>
<td>Can be developed, or availed through present players in the field.</td>
</tr>
<tr>
<td>13</td>
<td>Platform surveillance system</td>
<td>Can be developed indigenously</td>
</tr>
<tr>
<td>14</td>
<td>Design, development, testing and manufacturing of high power, low loss, low weight, under-slung transformer, preferably with aluminium tank, of above 6-6.5 MW power suitable for high frequency switching 4Q converter with harmonic control, hotel load and auxiliary windings.</td>
<td>Basic design may need outside consultancy. It can also be purchased from existing international suppliers.</td>
</tr>
<tr>
<td>15</td>
<td>Propulsion converter with IGBT (or any other type of device which is likely to be released in future) giving highest standards of power quality and near unity power factor at the pantograph</td>
<td>In the recent past, this item has been developed indigenously and is in commercial operation. Industries will be able to upgrade it to 6-6.5MW levels. It can also be purchased from existing international suppliers.</td>
</tr>
<tr>
<td>16</td>
<td>Traction motors with fully suspended arrangement, both synchronous and asynchronous type of capacity of about 1.5 MW torque transmission arrangement for withstanding above 400 km/h</td>
<td>Basic design would need outside consultancy. It can also be purchased from existing international suppliers.</td>
</tr>
<tr>
<td>17</td>
<td>High speed pantographs</td>
<td>Basic design would need outside consultancy. It can also be purchased from existing international suppliers.</td>
</tr>
<tr>
<td>18</td>
<td>High speed bogie and suspension arrangement</td>
<td>Basic design would need outside consultancy. It can also be purchased from existing international suppliers.</td>
</tr>
<tr>
<td>19</td>
<td>Capability to model panto-Catenary interaction at high speeds, especially with multiple locomotives attached in a train as a ‘train set’ and evolve the most optimum configuration to prevent oscillations and current collection problems at high speed.</td>
<td>Will need outside consultancy</td>
</tr>
<tr>
<td>20</td>
<td>Data communication network between the locomotives in a train, between locomotives and carriages as well as to way side stations.</td>
<td>Can be indigenously developed</td>
</tr>
<tr>
<td>21</td>
<td>Train wide internet connectivity (wireless broadband) and Infotainment</td>
<td>Can be indigenously developed</td>
</tr>
<tr>
<td>22</td>
<td>Development of high speed OverHead Equipment (OHE)</td>
<td>Will need outside support</td>
</tr>
<tr>
<td>23</td>
<td>ERTMS (European Traffic Management System) Implementation</td>
<td>Can be indigenously developed but would take more time. Initially can be availed from international players operating in India.</td>
</tr>
<tr>
<td>24</td>
<td>Development of high power fuel efficient diesel engines and diesel locomotives for tracks which are non-electrified</td>
<td>Will need outside support</td>
</tr>
<tr>
<td>25</td>
<td>Development of high speed tracks</td>
<td>Will need outside support</td>
</tr>
<tr>
<td>26</td>
<td>Development of state of the art facilities and skill for maintenance of track, rolling stock and other fixed installations for high speed.</td>
<td>Will need outside support</td>
</tr>
</tbody>
</table>
3.1.2 Technologies related to Freight Operation

Heavy haul is considered to be one of the most efficient methods of increasing freight throughput, if proper technology is applied. Under this, many technology areas need to get developed, including

(i) wagons with higher payload to tare ratio,
(ii) use of higher axle load,
(iii) use of long trains with radio controlled distributed power (RDP),
(iv) use of long trains with wired distributed power (WDP) and
(v) IT enabled freight operations management service with end-to-end wagon tracking system.

The status of each technology and availability of resources is detailed in Table 3.2

3.1.3 Technologies related to Signalling and Traffic Management System

The type of signalling and traffic management affects the overall efficiency and safety of operation. European railways were the pioneers in evolving a standard for automation in this area – ETCS (European Train Control System) – which involves provisioning in both trackside and on-board the vehicle. Depending upon this provisioning and safety levels, there evolved ETCS levels 0, 1, 2 and 3. ETCS level 3, together with GSM-R evolves ERTMS, which also has levels 1, 2 and 3 depending upon the nature of track to vehicle communication[24].

ERTMS is now a proven technology and would be needed in the future for Indian Railways to achieve the planned objectives. This is complex, involves multi-disciplinary technologies, and needs huge investments. Developing totally indigenous systems would take enormous time, but to sustain in the future, possession of this technology with Indian industries (even with foreign tie-ups) would be essential. To begin with, this technology needs to be bought from proven sources with a phased plan for indigenisation.

3.1.4 Technologies related to safety

• Coaches with better crashworthiness

Design of coaches with better crashworthiness, which is an area that would need outside support, at least in the form of consultancy[25].

• Accidents at level crossings

Highest numbers of fatalities over IR occur due to accidents at unmanned level crossings. In ERTMS (The European Railway Traffic management) territories, interlocking of level crossing would be taken care of as part of the basic requirement. However, many level crossings, due to its low traffic (train vehicle units), are not financially justified. Alternative technologies must be developed in such cases to avert accidents. This can very well be achieved indigenously with available resources.

• Accidents due to extremism and vandalism

This is a requirement which is very difficult to implement. Suitable technology must be evolved to detect suspicious movements and extremist activities on the track. On the rolling stock side

<table>
<thead>
<tr>
<th>SL No</th>
<th>Associated Technology</th>
<th>Availability of Resources Indigenously</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Wagons with higher payload to tare weight ratio (above 3.5)</td>
<td>Outside support is needed. Involves use of special composite materials</td>
</tr>
<tr>
<td>2</td>
<td>Use of higher axle load (25t, 30t and 35t) progressively</td>
<td>Development may be possible indigenously. As the impact is on track and bridges, it would attract huge additional investments</td>
</tr>
<tr>
<td>3</td>
<td>Heavy Haul with RDP (Radio Controlled Distributed Power)</td>
<td>Indigenously possible to develop. Investment needed for long loops, dedicated freight lines and other logistics. Already limited versions of indigenous designs are in commercial operation</td>
</tr>
</tbody>
</table>
also, suitable surveillance mechanism must evolve to detect carrying of explosives and banned items. This could possibly be developed indigenously with available resources.

• Accidents due to fire
Better designs to avoid fire and also detection and extinguishing technologies must be evolved.

3.1.5 Technologies related to security
A better surveillance and vigil mechanism is needed to curb crimes in moving trains and station areas. Technological tools like the following should be considered:

(i) Development of on-board CCTV surveillance: real-time monitoring is possible by a police squad in a nominated area in every train, for instance in the guard’s van. In such a case, there is no need for police to patrol the entire train in case of vestibule trains;

(ii) Development of systems that can be enabled by passengers in case of any security issues like terrorism and banditry attacks. These systems can take a snapshot and send to the on-board police control room for quick action;

(iii) New station designs for better surveillance;

(iv) New station designs for evacuation of public in the event of disasters caused by terrorists;

(v) New yard designs, which prevent access to unauthorised persons and/or facilitate remote monitoring and policing;

(vi) Systems (intended for installation at railway stations) for detection of explosives, inflammables, etc;

(vii) Ability of railway coaches to detect the on-board presence of explosives, inflammables, etc;

(viii) Ability of rolling stock to detect if explosives are planted on tracks or if damage has been inflicted to track by terrorists and transmit warning message to control centres;

(ix) Ability of railway infrastructure’s inspection cars/ trains to effectively detect and issue advance warning if explosives are planted on tracks or if damage has been inflicted to track by terrorists;

(x) Coach design should facilitate efficient evacuation of passengers in event of an explosion/ disaster;

(xi) Securing transportation of strategic importance e.g. defence supplies, emergency relief consignments, etc. from terrorist strikes;

(xii) Efficient system for security scanning of freight being received/ booked for movement;

(xiii) Systems for detecting suspicious activities in yards (i.e. planting of explosives on coaches, wagons, etc.); and

(xiv) Tamper-proof design of critical railway systems (e.g. rolling stock, signaling, relays, SCADA, etc.)

All the above aspects can be indigenously developed using available resources.

3.1.6 Technologies related to passenger comfort
• Riding comfort and tilting technology
Riding comfort is of paramount importance at high speeds. Passengers experience heavy force or jerks at curves due to centrifugal force, which can be eliminated if the cant (elevation) is adjusted suitably.

Tilting train technology can enhance passenger comfort through sensing the curves and tilts itself suitably to nullify the effect of centrifugal force. The Pendalino train of Italy uses the tilting technology. In case this technology is patented, the same can be purchased and used in India. An alternative strategy also can be explored.
• **Toilets and other facilities**  
There has not been any improvement in the design of toilets in trains. Efforts were made in the past with some type of bio-friendly toilets and collect-and-discharge type toilets. This environment friendly, low cost and robust technology jointly owned by IR and DRDO, is the first of its kind in Railway Systems in the world. However because of the nature of traffic, duration and type of logistics used are quite different in railway than in aircrafts, a suitable technology needs to be developed to make toilets as familiar to that of an aircraft.

• **Multi-modal station designs and facilities for persons with disability**  
Enough has not been done to make the travel of differently-abled and aged persons comfortable. The height difference between the platform and carriage floor in many stations, makes it difficult for aged and disabled persons to enter and exit. A special carriage can be designed and attached with every train and in such a special carriage, a few seats/ berths can be allotted for differently-abled and aged people. Further, coaches can be developed to suit persons travelling across the country for medical treatment. Even moving from one platform to another at short notices, during sudden announcements of platform change, becomes a nightmare.

3.1.7 Technologies related to energy management and environment issues, Power supply arrangement

The power requirement of a high-speed train is enormous. Each power head may be of the order of 6MW, and for a normal train configuration, 2 to 3 such units may be attached in one train, making the requirement above 12-18MW. The traction substation capacity and spacing needs augmentation. Presently, single phase is used for traction, and this may continue in future as well, till a path breaking technology is developed to make the present scheme obsolete. In order to balance the grid, three phases are staggered and fed to the OHE in successive substations. This requires creation of neutral sections in the OHE segregating different phases. The driver is required to switch off the loco circuit breaker before entering the neutral zone and again switch on after passing the neutral zone. This is becoming difficult even at the present speeds of 130-140 km/h, especially at night with poor visibility. It also adds stress to the driver.

For high-speed operation, an automatic mechanism is needed to detect the neutral zone and switch off and switch on the circuit breaker without the intervention of driver. But in this case, there will be loss of power for some time, which may affect the average speed. A better method would be to dynamically shift the neutral section so that there is no need to switch off the locomotive power. Some countries have already developed this technology. India needs to develop and perfect it.

(i) **Energy efficient traction – more regeneration**  
Energy efficiency must become the keyword for design of any equipment. Every type of electric traction rolling stock must have regenerative capability and feedback to the grid. The new generation fleet is being produced with regenerative capability. Railways must review the useful life of the old fleet of rolling stock and depending upon the financial viability, develop suitable energy recovery devices. This could involve changeover to a new type of converter for energy recovery.

(ii) **Captive development of renewable energy sources/alternate fuels for traction**  
Although Railways being known as one of the environment friendly mode of transport as compared to roadways, there is a steady increase in the fuel bill. The second largest expenditure of Indian Railways is fuel, both electric and fossil fuels. Hence the need of the hour is to shift towards renewable sources of energy and alternate fuels. Alternate fuels like Bio-diesel, CNG/ LNG are cheaper than diesel and have potential to replace diesel as a preferred choice for traction fuel globally. Suitable IC engines must be developed to take care of the alternate fuels.

(iii) **Development of Hydrogen fuel cell based locomotives/EMUs is another option**  
Next generation vehicles are expected to be working on fuel cells. It would be advisable to initiate a technology development project of hybrid electric-cum-fuel cell locomotives. The initial development can be aimed at low power shunting engine or a rail car.

(iv) **Use of solar power for station lighting and ventilation**  
Progressively, the station lighting and ventilation must get shifted to solar power. Suitable technology and industries are to be identified for achieving this objective.

(v) **Smart railway energy grids**  
The traction power requirement is diverse and varies widely. It is difficult to maintain a constant...
demand pattern as required by state electricity boards. In future, a separate smart energy grid may be developed, through which, better energy planning and management is possible.

(vi) Waste management for trains, stations
Keeping Indian trains and stations clean is possible only by the use of appropriate technology. Suitable technology needs to be developed and waste must be re-cycled for generating energy.

(vii) Tapping piezo-electric power (floors) for station energy needs
In busy railway stations like New Delhi, Mumbai, Kolkata and Chennai, the principle of piezoelectric power can be used for generating part of the station energy requirement. It would be interesting to develop suitable technology to derive piezoelectric power from the floors of station area made of piezoelectric crystals. Simultaneous use of piezo-electric principle for deriving power for level crossings (for audio visual warning) also may be explored. In this case, piezo-electric mats may be kept between rail and sleeper or below the sleeper, allowing energy to get stored during passage of the train.

(viii) Use of complete renewable sources for station energy requirement
Indian Railways should identify stations, wherein the entire station energy requirement is generated through renewable sources. This can be done by designing a suitable multiple source local energy grid for station applications. The energy sources, which may be connected to the grid, can include solar, wind and biomass (from the waste generated in the trains, station area and surroundings).

(ix) Computer assisted driving and cruise control
This will bring in energy saving and optimum time of travel.
4.1 CAPACITY AUGMENTATION
Between now and 2035, the passenger and freight traffic in India is expected to grow by another 40% and 37% respectively. However, while both passenger and freight traffic has shown phenomenal growth, the inputs have not grown at this rate. Though railways have evolved from steam to diesel to electric traction, and also adopted a uniform gauge policy (broad gauge), technological intervention has been rather slow and also out of pace with the global standard of development.

Technology intervention is needed in the following key areas –
(i) maximum speed and average speeds of passenger trains,
(ii) average speeds of freight trains and
(iii) load carrying capacity of wagons.

The above three key enablers will need further technology intervention in many associated disciplines, including
• high speed trains with tilting technology,
• higher axle load wagons,
• tracks suitable for higher axle load,
• better payload to tare weight ratio,
• signalling and communication systems for safe operation,
• use of energy efficient systems,
• other passenger amenities and facilities.

One of the following options can be adopted in increasing the throughput of passenger and freight trains:

a) Developing an exclusive freight network, connecting major centres of business, originating points of minerals, ores and ports. This will ease out the freight traffic from the existing mixed lines. Augment the existing network for higher speed, which must be used for passenger traffic and freight feeder service only.

b) Alternative to the above could be developing exclusive high speed passenger network connecting state capitals, existing major railway junctions, centres of business, and airports. In this scenario, existing network must be used predominantly for freight traffic and for passenger feeder services.

Two dedicated freight corridors between Delhi-Kolkata and Delhi-Mumbai are now being built. In parallel, railways have also set-up another corporation for building a high speed rail corridor (HSRC). However, unless these two agencies plan and build passenger and freight networks with seamless integration and with due coordination of the railway ministry, the future vision will not be fulfilled. The latter option is preferred, as it will cause least disturbance in changing over from the present to the future.

Passenger traffic has to be dealt under the three categories mentioned below:

(i) Long distance travel involving a night or part of a night requiring sleeper facilities;

(ii) Medium distance involving four to five hours of travel (example business travel);

(iii) Short distance commuting, involving less than two hours of travel and including suburban and urban transport like metro rail.
For passenger capacity increment under category (i) and (ii) above, following options are possible:

1. Dedicated high-speed passenger corridor, similar to ICE, TGV and SHINKANSENG connecting state capitals, national capital, important business centres and towns;

2. Feeder services to this high-speed network using the existing rail connectivity or by way of incremental additions;

3. Raising the maximum operating speed to 350 km/h and establish an average speed of at least 300 km/h. Please note that many countries, including China, have already developed this capability;

4. Make the passenger fare different for long distance and medium distance travel to discourage medium distance travellers from using long distance trains. Such variable fare can be linked with availability of seats. During lean periods, if there is excess capacity in long distance travel, the same can be given at a subsidised rate.

Following towns/cities can be considered for inclusion in the high speed network:
- New Delhi, Chandigarh/Kalka, Jaipur, Kanpur, Lucknow, Allahabad, Varanasi, Gorakhpur, Patna, Guwahati, Kolkata, Ranchi, Asansol, Kharagpur, Tatanagar, Raipur, Bhubaneshwar, Nagpur, Bhopal, Indore, Vadodara, Ahmedabad, Mumbai, Pune, Hyderabad, Vijayawada, Visakhapatnam, Chennai, Bangalore, Madurai, Kanyakumari, Ernakulam, Mangalore, Goa, Coimbatore, new Capital of Andhra Pradesh, Jammu. The above are only suggestive; however, the whole situation should be reviewed considering the socio-political requirement.

For short distance commuting, the following two aspects should be considered:

1. To decongest our roads in Tier I and Tier II cities, metro railway network is a must. It also minimises environmental pollution.

2. The high-speed network can be managed by an independent body and the feeder network, which would be part of the existing network, can be under Indian Railways.

As a natural consequence of the above two aspects, a stream of associated technologies are to be developed. Metro network is already in place for quite some time now, but high-speed operation is totally a new area.
4.2 PRIORITISATION AND MILESTONES

The future technologies to be developed for the identified goals, can be taken up in three phases, viz. (i) short, (ii) medium and (iii) Long term. Considering a horizon period of 2035 under consideration, short, medium and long can be respectively treated as within five years, five to 10 years and beyond 10 years. The anticipated technologies in future can be classified as mentioned in Table 4.1.

**TABLE 4.1: TECHNOLOGIES REQUIRED**

<table>
<thead>
<tr>
<th>INFRASTRUCTURE LEVEL</th>
<th>Term</th>
<th>Technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short Term (0-5 years)</td>
<td>Dedicated high speed tracks on select demonstration routes</td>
<td></td>
</tr>
<tr>
<td>Medium Term (5-10 years)</td>
<td>Dedicated high speed tracks connecting quadrilaterals and diagonals</td>
<td></td>
</tr>
<tr>
<td>Long Term (10-20 years)</td>
<td>Dedicated high speed tracks connecting all state capitals</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dedicated high speed tracks connecting other important business centres</td>
<td></td>
</tr>
</tbody>
</table>

**OPERATION LEVEL**

<table>
<thead>
<tr>
<th>Term</th>
<th>Technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short Term (0-5 years)</td>
<td>High Speed Operation @ 200 km/h</td>
</tr>
<tr>
<td></td>
<td>Heavy Haul Operation – Train Load 10,000t</td>
</tr>
<tr>
<td></td>
<td>Signalling and Traffic Management System – ERTMS coverage in quadrilaterals and diagonals</td>
</tr>
<tr>
<td>Medium Term (5-10 years)</td>
<td>High Speed Operation @ 250 km/h</td>
</tr>
<tr>
<td></td>
<td>High Speed Operation @ 300 km/h</td>
</tr>
<tr>
<td></td>
<td>Heavy Haul Operation – Train Load 20,000t</td>
</tr>
<tr>
<td></td>
<td>Heavy Haul Operation – Train Load 40,000t and above</td>
</tr>
<tr>
<td></td>
<td>Signalling and Traffic Management System – ERTMS coverage in A and B routes</td>
</tr>
<tr>
<td></td>
<td>Signalling and Traffic Management System – ERTMS coverage in all routes</td>
</tr>
<tr>
<td>Long Term (10-20 years)</td>
<td>High Speed Operation @ 350 km/h</td>
</tr>
</tbody>
</table>

**OTHER AREAS**

<table>
<thead>
<tr>
<th>Term</th>
<th>Technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short Term (0-5 years)</td>
<td>High speed test track</td>
</tr>
<tr>
<td></td>
<td>Simulation Studies of high speed trains</td>
</tr>
<tr>
<td></td>
<td>Composite materials for coaches – lighter, stronger</td>
</tr>
<tr>
<td></td>
<td>Crashworthiness studies, crashworthy coaches, aerodynamic designs</td>
</tr>
</tbody>
</table>
### Short Term (0-5 Years)
- Suspension Technologies for high speed coaches including tilting technologies
- High speed tracks (in stages 200, 250, 300, 350)
- Higher axle load wagons in stages of 25t, 30t, 35t
- Tracks suitable for higher axle loads 25t, 30t
- Night vision technology for driving at night
- Environment friendly and user friendly toilets implementation in stages
- Computer and GPS assisted cruise control for energy saving
- State of the art maintenance infrastructure and skill development for track, rolling stock and other fixed installation along with the introduction of new technologies.

### Medium Term (5-10 Years)
- Tracks suitable for higher axle load 35t
- Alternative fuel based locomotives (fuel cell)
- Computer and GPS assisted cruise control for energy saving
- Total driverless operation (for select high speed lines and all metros - Driver may be available as a backup protection only)

### Long Term (10-20 Years)
- Inter-vehicular couplers for high speed
- Door closing mechanism
- Platform and train security surveillance system
- High Power Traction propulsion Components (both electric and diesel electric traction)
- Diesel Engines working on substitute fuels (bio-diesel)
- High speed pantograph
- High speed OHE, capability to study high speed panto-OHE interaction
- Implementation of wireless broadband internet and infotainment/passenger information system in all important passenger trains
- High speed tracks (in stages 200, 250, 300, 350)
- Wagons with payload to tare weight ratio above 3.5
- Higher axle load wagons in stages of 25t, 30t, 35t
- Tracks suitable for higher axle loads 25t, 30t
- IT enabled freight operations including RFID based tracking
- Environment friendly and user friendly toilets implementation in stages
- Predictive Maintenance Technologies for track and rolling stock (Wheel Impact Load Detector, Acoustic bearing defect detection, Hot axle detection etc)
- Accident Avoidance System (Train Collision Avoidance System)
- State of the art maintenance infrastructure and skill development for track, rolling stock and other fixed installation along with the introduction of new technologies.
5.0 IMPLEMENTATION STRATEGY

5.1 KEY ENABLING TECHNOLOGIES
Out of various requirements discussed in the foregoing chapters, only key enabling technologies are discussed in this chapter, along with the strategy for development, with suggested time frame. These include:
(i) high speed operation,
(ii) heavy haul operation,
(iii) signalling and traffic management system, and
(iv) passenger amenities.
Details are given in Table 5.1.

5.2 HIGH SPEED OPERATION
The high speed operation is highly multi-disciplinary, involving various technologies involving track, rolling stock, signalling, safety and security. In some select areas, technology may have to be acquired from developed railways initially. Making a pilot high speed operation in the medium term will provide opportunity to understand and assimilate various complex issues of high speed. The success will depend upon the synergy with which various departments of railways (electrical, mechanical, civil, signal, etc.) will work and involve proper industries. The role of RDSO is also very important in synergising these agencies.

### TABLE 5.1: STRATEGIES FOR TECHNOLOGY DEVELOPMENT

<table>
<thead>
<tr>
<th>SL No</th>
<th>Requirement</th>
<th>Indigenous</th>
<th>Foreign Direct/ Collaboration</th>
<th>Strategy</th>
<th>Time Frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>High Speed Operation</td>
<td>-</td>
<td>Yes</td>
<td>• Import initially.</td>
<td>• 200 km/h : 2-5 years</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Indigenous development to follow through collaboration / TOT</td>
<td>• 250 km/h : 4-8 years</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• 300 km/h : 6-10 years</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• 350 km/h : 8-12 years</td>
</tr>
<tr>
<td>2</td>
<td>Heavy Haul Operation</td>
<td>Yes</td>
<td>-</td>
<td>• Associate with present brake system suppliers.</td>
<td>• 10,000t trains : 2-5 years</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Technology input through TOT/consultancy from foreign sources on select areas, if needed.</td>
<td>• 20,000t trains : 3-7 years</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• 40,000t trains : 5-9 years</td>
</tr>
<tr>
<td>3</td>
<td>Signalling and Traffic management System</td>
<td>Partially</td>
<td>Yes</td>
<td>• Import initially.</td>
<td>• ERTMS coverage of Quadrilaterals and Diagonals : 100% in 3-5 years</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Indigenous development to follow through collaboration / TOT</td>
<td>• ERTMS coverage in all Class A and Class B routes : 100% in 4-8 years</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• ERTMS coverage in all A, B, C and D class routes : 100% in 6-10 years</td>
</tr>
<tr>
<td>4</td>
<td>Passenger Amenities</td>
<td></td>
<td></td>
<td>Indigenous development</td>
<td>1-2 years</td>
</tr>
<tr>
<td>4.1</td>
<td>Railway Stations with intermodal commuting facilities and convenience for aged and persons with disability</td>
<td>Yes</td>
<td>-</td>
<td>Indigenous development</td>
<td>1-2 years</td>
</tr>
</tbody>
</table>

154 RAILWAYS
5.3 HEAVY HAUL OPERATION

Heavy haul operation is a method to drastically improve the throughput with minimal input. A long train is operated using a single crew by distributing the locomotives along the train and controlled through radio signal. Australia, China, USA and South Africa are the countries operating heavy haul trains; with trains of length up to 7.3 km being in operation. This technology can be indigenously developed and implemented in potential routes, especially in dedicated freight lines, in the medium-term. This scheme with limited scope is already indigenously developed and is in commercial use. This can be extended for developing heavy haul trains at par with developed countries.

5.4 SIGNALLING AND TRAFFIC MANAGEMENT SYSTEM

Implementation of systems like ERTMS (European Rail Traffic Management System) is inevitable for safe and efficient running of trains at high speed. Being in vogue in developed countries, adequate literature and knowledge can be acquired for its indigenous development. Suitable industrial partners are to be brought in for successful development and implementation.

5.5 PREDICTIVE MAINTENANCE TECHNOLOGIES

Predictive maintenance technologies involve identification of a possible defect (which can cause huge loss or accident) in advance. This can consist of various technologies like:

1. Wheel impact load detector installed by the side of the track to identify the defective wheels of a train and send message to the maintenance depot instantly to isolate such defective coaches or wagons.
2. Acoustic based bearing health check.
3. Infrared based hot axle detection, remote diagnostic of locomotives and coaches, real-time monitoring of bridges and structures, etc. All these technologies can be developed indigenously and deployed in the short-term.

5.6 ACCIDENT AVOIDANCE SYSTEM

Collision can be avoided by suitably deploying a collision avoidance system. This can be developed indigenously and deployed in the short-term. Other technologies for avoiding accidents in level crossings and also due to fire can also be developed indigenously and implemented in the short-term.
As can be seen, technology progress in the railways sector has been rather stagnant, in the last decade. The pace of growth inputs has not been able to keep up with the increase in freight and passenger traffic. The running route km and track km, the maximum and average speeds of both passenger and freight trains, signalling and communication system, safety measures for operation, maximum axle loads, payload to tare ratio, etc. have almost remained static.

In order to catch up with global standards, a leap forward is needed over the next two decades. A totally new mechanism of technology management and monitoring is required for implementing the identified technologies within the proposed time frame.

Unfortunately, the structure of the Indian Railways is not conducive for fast technology development. The positive aspect, nonetheless, is the availability of all these technologies for purchase at a price. In the years to come, only an indigenous development approach is deemed sustainable. For successful development, one has to blend indigenous technology along with acquired global technology in select critical areas. This will speed up the implementation and milestones can be maintained.

Key enabling technologies like high speed passenger operation, heavy haul operation, higher axle load, lighter wagons, crashworthy coaches, communication-based train operation, and driver less operation, among others, will pave the way for developing many associated technologies. This will boost the rail industry in India, and at some point in time, India can reach at par with developed countries.

The success of the identified technologies and development milestones will become realistic if adequate funds are made available in time and the work entrusted to appropriate agencies, both government and industry and monitored properly.
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WATERWAYS
1.0 INTRODUCTION

Of the four modes of transport, water transport is the most economical and environmentally friendly. Over 90% by volume and 70% by value of international trade is transported by sea routes through ships.

Mr Ethimios E. Mitropolous, former Secretary-General of the International Maritime Organisation (IMO) had once said, “But for shipping, half the world would have starved to death and the other half would have perished because of freezing cold.” The importance of shipping to the world economy could not have been emphasised better.

A truly global industry, shipping has its prospects closely linked with the level of global economic activity. A higher level of economic growth in one part of the globe would generally lead to higher demand for industrial raw materials and finished products. This in turn will lead to growth of exports and imports through international shipping.

Predicting the future is difficult; nonetheless, goals have to be set. It is envisaged that growth of world population and economy will lead to a corresponding growth in demand for goods and services across the world. High growth markets will become the driving economic forces in the world, paving the way for shift in trade patterns and increase in international shipping activities.

Further, as a consequence of shore-based megacities, congestion on land, and a general demand for regional transport of goods and people, there will be an increase in coastal shipping activities in all parts of the world.

As far as India is concerned, shipping is one of the most important transport modes with huge potential for growth as we have around 7,500 kilometres of coastline studded with 13 major and 200 minor & intermediate ports, which can be used as the gateway for trade to and from the vast hinterland having around 14,500 kilometres of navigable rivers and canals.
1.1 SHIPPING: A VIABLE ALTERNATIVE

India is the world’s third largest energy consumer, and its energy use is projected to grow at a rapid pace supported by economic development, urbanisation, improved electricity access and an expanding manufacturing base.

Shipping provides energy security to our country by maintaining the supply of crude oil at all times as India is heavily dependent on its import. Growth of our economy has led to a number of coal-fired power plants coming up across the country, but with limitations on mining as well as calorific values of indigenous coal, these plants depend heavily on coal import through shipping. Thus, here too, the shipping is adding on to energy security of our nation.

Further, shipping is known to be the second line of defence for any nation and in case of any disturbance due to geo-political reasons, Indian flag ships can always be pressed into service for protection of the national borders and trade by maintaining the transport linkage.

Besides international shipping, coastal and inland shipping are equally important in the Indian context, as these offer significant advantages over road and rail transport in terms of fuel and cost savings as well as environmental benefit. Increasing delays in transporting goods due to high road and rail congestion is going to force the adoption of waterways as a preferred mode of transport and will provide impetus to the growth of coastal and inland shipping network in India in the future.

1.2 INFRASTRUCTURE

For promotion of water transportation, creation and development of shipping infrastructure is equally important. This may include but is not limited to ship building industry, port facilities, human resource and other logistics. It has been established by various studies carried all over the world that shipping has a multiplier effect on the economy.

It is estimated that for every $1 in revenue earned by an Indian flagged vessel, about 67 cents gets ploughed back into the Indian economy, whereas for every $1 in freight paid to a foreign flag vessel, only 10 cents flows back into Indian economy. Therefore, the growth of Indian shipping has the potential to act as a catalyst in the development of several other allied industries, leading to growth of our economy and enhanced employment opportunities for Indians.

From the foregoing, it can be envisaged that merchant navy is vital to India’s economy and power. The maritime sector of India was among the finest in the world right from the days of the Indus valley civilisation. History teaches us that our nation was prosperous and influential when we were strong at sea and we were subjugated when we lost our strength at sea. In present and future contexts also the importance of a strong and superior Indian maritime sector as well as associated logistics infrastructure cannot be ruled out.

The future of maritime transport lies in the development of “greener ships” with least harmful emissions by fully harnessing the technological advancements. The safety and security aspects of maritime transportation will also need to be addressed simultaneously. These will be achievable through investments in research & development (R&D), firm control over ECONOLOGY (Economy + Ecology + Technology) and solid government support.

The transformation of India’s maritime transport sector, therefore, needs a clear, long-term and sustainable vision encompassing initiatives that are proactive for it to flourish and regain its lost glory.
Shipping is a complex and volatile industry. The industry is cyclical by nature and has experienced many peaks and troughs in the past. World economic growth and the demand for seaborne transport are closely linked. A general observation is that during periods of low world Gross Domestic Product (GDP) growth, the volume of seaborne trade shrinks and vice-versa. This volatility in the shipping industry creates a potential for high profits, but also for considerable losses as shown in fig 2.1 and 2.2 below.

2.1 GLOBAL TRENDS
Globalisation and rapid development of Asian economies has led to a great deal of added demand in the shipping market since 2002. This has resulted in unprecedented contracting of new tonnage, boosting the order book for new vessels’ construction by as much as 500%. With the financial crisis of 2008, the world trade started shrinking dramatically. The vessels that were ordered during the market boom are now being delivered, adding to the current tonnage. Naturally this created a substantial oversupply of tonnage in the market, which inevitably led to depressed freight rates and weak markets in general.

The current reduced level of world economic growth, coinciding with overcapacity in the global fleet, has led to the shipping industry currently

FIG 2.1: THE OECD INDUSTRIAL PRODUCTION INDEX AND INDICES FOR WORLD GDP, MERCHANDISE TRADE AND SEABORNE SHIPMENTS (1975-2014) (BASE YEAR 1990 =100), [1]

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**FIG 2.1:** THE OECD INDUSTRIAL PRODUCTION INDEX AND INDICES FOR WORLD GDP, MERCHANDISE TRADE AND SEABORNE SHIPMENTS (1975-2014) (BASE YEAR 1990 =100), [1]
experiencing tough conditions. It will take some years before the current oversupply of tonnage is absorbed by the shipping industry.

Looking ahead, according to Det Norske Veritas (DNV), the Norwegian classification society study, the total world GDP growth on an average is expected to remain fairly stable at approximately 3.3% annually through 2030. The capacity of the world fleet is also expected to grow accordingly. Marine Intelligence & Publications; IHS Fairplay estimates that the total world fleet, measured in million Deadweight tonnage (DWT), will increase by approximately 50% between 2013 and 2020, based on this annual economic growth of 3.3%. This suggests that on an average, 1,700 to 2,000 new vessels will be contracted for each year.

2.2 INDIA VIS-À-VIS GLOBAL TRENDS
India has substantial potential considering its long coast line and possible growth of Inland Shipping. A comparison of what we have achieved as against global trends in respect of different aspects of shipping, is done in the following paragraphs:

2.2.1 Indian Shipping Tonnage
(a) As on 1st January 2015, Indian shipping fleet consisted of 1174 vessels (361 Ocean going) of about 15.55 million DWT, as against world merchant fleet comprising of 89,464 vessels with a total tonnage of 1.75 billion DWT [United Nations Conference on Trade and Development (UNCTAD),Review of Maritime Transport, 2015]. That makes the Indian shipping tonnage at just about 1% of the world fleet, ranked at 19th position in the world. The share of Indian shipping companies in transportation of India’s international trade has declined from over 90% in the 1950s, to 30% in the early 90s, to less than 9% presently. Liberalisation of the economy in the 90s saw a surge in India’s international trade, which grew at a much faster rate than that of the shipping tonnage. Slow growth of tonnage led to gradual decline in the Indian shipping companies’ share in transporting its trade. Thus, making our nation vulnerable as it remains heavily dependent on foreign shipping companies for its transportation need, which indeed poses a threat to our national as well as energy security.

The share of Indian shipping companies in transportation of India’s international trade

![Graph: Growth in the world fleet and total seaborne trade (forecast included)](image-url)
(b) India’s merchandise trade was in the region of $757 billion in the year 2015 (Ministry of Commerce & Industry, Govt. of India). UNCTAD study states that the freight cost of the countries such as that of India is about 7.4% of the value of merchandise trade. On this basis, Indian trade paid a freight of approximately $56 billion in the year 2015. However, due to non-availability of adequate Indian tonnage, about 90% of this freight bill was passed onto foreign shipping companies. The amount of foreign exchange being lost by the country due to this imbalance is phenomenal.

(c) Amongst various cargo categories, crude oil continues to be the most vital commodity required by India. Out of 223.242 MMT of crude processed in refineries in 2014-15, the domestic production was only 37.461 MMT [3] implying imports were over 84% of the country’s total crude oil requirements. Oil tankers constitute over 61% of total Indian shipping fleet as against international average of tankers constituting one-third composition of the fleet.

(d) In bulk trade, the scenario is no different. As one of the fastest growing economies, India’s requirement for imported coal (both thermal coal and coking coal) has increased manifold. However, the percentage of this imported coal carried by Indian ships is barely 5~6%. Huge fluctuations in freight rates are also one of the factors responsible for lack of investment in this sector. The Baltic Dry Index which provides an assessment of freight rates for moving the major raw materials like coal, iron ore and food grains by Sea was as high as 2000 on Oct 7, 2012. It slumped to a low of 647 signalling the start of crisis in dry bulk market, fig 2.3 (UNCTAD, Review of Maritime Transport, 2015). It fell to a historic low of 298 points on February 4, 2016 (Lloyd’s List). Unless the Indian ship owners are assured of continuous and unstinted support by the trade, they would remain reluctant to buy dedicated tonnage to serve Indian bulk trade requirements, as this entails risk and huge capital investments.

(e) According to statistics available with the Shipping Corporation of India Ltd as on 01.02.2016, the share of Indian shipping companies is alarmingly low in container trade as well, at less than 4% of the total container trade of India. With the economy booming and recent opening up of retail sector to foreign players, the FMCG sector is likely to get a big boost. Despite such a good market, for a nation with over 1.2 billion population, barring the national shipping
carrier Shipping Corporation of India, no other Indian shipping company is willing to enter this sector. At 51% containerisation level, India continues to be behind developed countries, where containerisation of general cargo is up to 70-80%. The level of containerisation in India is bound to increase in future and unless the liner tonnage of the country increases, Indian companies' share would decline even further.

(f) In the interest of national trade, economy and security, it is necessary, therefore, to develop a strong Indian merchant fleet having balance representation of all the above segments.

(g) One of the major challenges faced by Indian shipping is lack of cargo support. In countries like USA and Brazil, Cabotage regulations are strictly followed, whereby all domestic cargo is transported by ships that are indigenous built as well as registered under the national flag. However, in India, Cabotage regulations have regularly been waived off enabling foreign shipping lines to transport India's domestic cargo between two Indian ports. India needs to adopt similar Cabotage and cargo support policies like rest of the world in order to improve Indian tonnage to respectable levels.

(h) Lack of financial incentives has been the other major challenge faced by the Indian shipping companies, thus hampering their growth. Introduction of the tonnage tax system in 2004 in lieu of income tax, which allows Indian shipping companies to pay fixed taxes based on their tonnage irrespective of their earnings, was a major step towards creating a level playing field for the Indian ship owner. However, the entire tax structure in the country needs to be rationalised and brought in line with other maritime nations, which offer tax free regime to shipping.

2.2.2 Costal Shipping/Inland Water Transportation

(a) India has a huge coastline of 7,517 km, and has 14,426 km of navigable inland waterways. Of these, 36% of major rivers and 3% of canals are conducive to the movement of mechanised vessels.

(b) Although, the promotion and the use of coastal shipping and inland waterways was considered as important in the past very little has been done so far.

(c) Presently, the share of inland shipping is a meagre 1%, while coastal shipping constitutes 7% of the total domestic cargo movement in India. In comparison, nearly 36% of freight, amounting to about 1.9 billion tonnes, is moved around Europe through coastal waters. Other Asian countries such as China and Indonesia have also exploited their coastal waters to a much larger extent. India's coastal shipping potential thus remains significantly underutilised as compared to other emerging and developed nations.

(d) Inland Waterway Transport (IWT) in India grew at an average of 7.2% during the 11th five year plan period. While IWT cargo traffic was estimated at 79 MMT in 2011-12, India still falls short in its share of IWT at less than 1% as compared to China's 8.7%, the USA's 8.3% and Europe at 7%.

(e) The foremost benefits of coastal shipping and inland water transportation are:

(i) It is environment friendly, fuel-efficient and safe as compared to road and rail transport.

(ii) The value of fuel consumed by water transport is 30% of that consumed by road. If one takes into account the diesel subsidy given to the road sector, the...
cost becomes as low as 26% of the fuel consumed by road.

(iii) According to the World Shipping Council, emissions from ships are one-sixth of that by road and one-half of those emitted by rail.

(iv) Coastal shipping would help reduce concentration of traffic on the already strained road network of India.

(v) Coastal shipping is much better suited for handling large parcels, which rail and road networks cannot compete with because of size and infrastructure constraints, especially cement, iron ore and coal.

(vi) It entails optimal use of India’s natural advantage and resource — a long coast line and a wide network of rivers in many parts of country.

(f) Given that India is blessed with a long coastline, coastal shipping has been identified as a major potential growth area for the Indian economy offering enormous benefits to the Indian commercial activities.

(g) As the need for capacity enhancement accelerates over the coming years, it would be inevitable to consider coastal shipping as a strong option to ease the pressure on roads and railways. It is estimated that the nation would save an estimated INR 15-20 billion through diversion of 5% of cargo from road to coastal shipping.

(h) One of the major challenges restricting growth of coastal shipping in India is that we do not have an integrated transport policy, or an institutional mechanism that encourages and promotes inter-modal coordination. This has resulted in different modes competing with each other leading to sub-optimal use and allocation of resources. Instead, a more integrated transport system with reasonable share of road, rail, coastal and inland shipping needs to be developed.

(i) Non-availability of adequate draft is the other impediment to the development of coastal shipping, as ship owners prefer to operate coastal vessels having draft of 7-9.5 metres due to its economic feasibility. Adequate depth for such vessels is not available at most of the non-major Indian ports. Even a river-sea vessel would require a draft of around 3.5 metres for carrying out coastal operations economically. Addressing this problem would entail large scale dredging operations of the port and river channels.

(j) Lack of port infrastructure in the inland regions and along the river channels capable of accommodating small vessels and barges is also a hindrance to the growth of inland shipping.

(k) The approach roads leading to ports are narrow, making them unsuitable for containers/cargo movement. The inefficient and underdeveloped supply chain becomes a bottleneck in the development of coastal shipping and renders end-to-end logistics costs uneconomical, while also increasing transportation time.

(l) Non-availability of concessional finances for acquisition of coastal vessels, cumbersome customs procedures, lack of quality manpower, high import duties on bunker oil and spares are some of the other challenges that need to be addressed.

2.2.3 Shipbuilding

(a) Shipbuilding traces its routes to pre-recorded history and was one of the prosperous industries in ancient India. History shows us that the evolution of nations as manufacturing powerhouses during various periods of time has a strong association with their shipbuilding capabilities. The shipbuilding industry has been amongst the most dynamic of the maritime sectors with the industry shifting dominance from country to country. The British during early part of 20th century, the Americans during post second world war, the Japanese during 1960-90, the Koreans post 1990 and China since early 2000 with almost 50% share, have become the undisputed leader in commercial shipbuilding.

(b) The consistent growth in Indian economy since 1990s, coupled with unprecedented boom in commercial shipbuilding sector worldwide in the period commencing 2002, gave ample scope to the Indian shipbuilding industry for growth. In the 10th five year plan period (2002-2007), wherein a subsidy scheme (30%) was granted by the Government of India to create a level playing field for the Indian shipbuilders, India’s
share in commercial shipbuilding increased from a meagre 0.12% to about 1.3%. The growth though of a very small magnitude on worldwide basis, was significant from Indian perspective.

(c) During this boom there was a dearth of available shipbuilding yards worldwide to fill the appetite of ship owners, who went on ordering for more and more ships. This scarcity of shipbuilding yards provided opportunities to Indian commercial shipbuilders to become a manufacturing option for the international ship owners. At that time, the Indian commercial shipbuilding industry ranked 5th globally with a market share of about 1.3% of world shipbuilding capacity. 90% of world shipbuilding capacity was divided between Japan, Korea and China.

(d) However, since 2007 the Indian commercial shipbuilding growth has declined substantially. After the withdrawal of the subsidy scheme, Indian yards no longer remained competitive against their Asian counterparts. India’s share slowly reduced to below 0.2%, which was the share prior to introduction of subsidy scheme for many years. Commercial shipbuilding industry is presently going through one of the toughest phases nationally as well as internationally, as overcapacity in every segment of shipping has made its survival very tough.

(e) The challenges faced by the Indian commercial shipbuilding industry, besides lack of government support, are also lack of system standardisation and system integration processes. Although ISI standard from Bureau of Indian Standards (BIS) exists, it is neither diligently enforced nor sincerely adopted by manufacturers and suppliers. Lack of standardisation of ancillary units significantly delays the delivery of ships. It takes as short as six months to deliver a vessel by South Korea, while Indian commercial shipbuilding yards take anywhere between 18 to 60 months, rendering the sector unattractive for global ship owners to place their orders.

(f) The Indian commercial shipbuilding sector can learn a lot from the agile and robust capabilities of Indian defence shipbuilding sector in terms of technology transfer. Shipbuilding industry is a highly technical and capital intensive industry and apart from generating employment, it also creates growth of several ancillary and support industries. This industry has a tremendous multiplier effect because of good employment potential and its economic impact is significant. All major shipbuilding nations like China, South Korea and Japan have reached top positions with active financial support by way of subsidy or reduction in taxes/duties from their respective governments.

(g) Without incentives from the government by way of subsidy or tax benefits, it would be extremely difficult for the Indian shipbuilding industry to survive. The Indian shipbuilding industry has been demanding a level playing field, including an “infrastructure status”. The government should seriously provide financial incentives and other logistics support for promoting shipbuilding industry in the country.

2.2.4 Port Infrastructure

(a) Ports are at the forefront in the logistics chain, and play a vital role in a country’s national trade and overall economic development.

(b) India’s total merchandise trade has increased over three-fold from $252 billion in 2006 to $757 billion in 2015. During the same period, the volume of cargo handled at ports increased from 636 million tonnes to 1052 million tonnes. In 2014-2015, total capacity of the country’s ports was 1,247 million tonnes as against which they handled 1052 million tonnes of cargo.

(c) Over the past five years, traffic at major ports has grown by a compound annual growth rate (CAGR) of 4%, while traffic at non-major ports has grown at a higher CAGR of 13.7%. This trend has resulted in
the proportion of traffic at major ports falling from 90% in 1995 to 60% during the 12th five year plan. Conversely, non-major ports have increased their proportion of traffic from 10% to 40% during the same period.

(d) The last decade’s significant growth in port traffic and cargo was on account of a boost in domestic consumption (higher imports) and impetus to the manufacturing sector (setting up of SEZs, incentives, etc. to promote exports).

(e) When major ports are conveying sluggish signals, non-major ports in the country are doing relatively better. Their better performance is driven by their more diversified cargo streams, higher capacity utilisation, and presence of captive cargo streams, superior operating efficiency and infrastructure, enabling diversion of cargo from congested major ports. This trend of non-major ports outpacing major ports in terms of cargo growth is expected to continue in the Indian port sector in the near future.

(f) Development of transhipment hub ports for handling of container traffic – both on the east and west coasts of India – is the need of the hour. In the container trade, Indian ports handled 7.96 million TEUs (Twenty Foot Equivalent Unit) in the year 2014-15 (Indian Ports Association), where TEU is the standard unit for describing the standard intermodal container dimensions.

Out of the above a good lot of containers are transhipped to some major transhipment hubs like Singapore, Colombo and Dubai. The reason such transhipment takes place is lack of adequate port infrastructure in our country. Indian ports cannot accommodate large sized vessels, which are preferred on long haul trades. While the world has moved onto vessels of up to 19224 TEUs carrying capacity, the largest vessel that Indian ports can handle is in the range of 6500 TEUs. Large vessels thus skip Indian ports and transship Indian containers at international transhipment hubs. The containers are then sent to India through feeder services linked to the hubs, which lead to increase in overall cost and time due to additional handling. Development of such transhipment hub ports on Indian coast would lead to reduction of our dependence on foreign ports for transporting Indian containers.

(g) For robust growth of Indian port infrastructure, faster regulatory clearances and appropriate tariff fixing are important issues.

2.2.5 Human Resource

(a) Seafarers are the most important link in the logistic chain of the shipping industry. They play the most crucial role in this industry because it is they who move the ship and its cargo to various destinations around the world. Philippine being the biggest supplier of manpower to the world merchant fleet as shown in Fig 2.4 below.

(b) The shipping companies place their most valuable assets – the ships and its cargo worth millions of dollars – into the tender care of the seafarers. The enormity of the responsibility placed onto handful of seafarers (approximately 20) sailing at the high seas can easily be understood. The knowledge and skill sets required for a good seafarer are, therefore, exclusive.

(c) Indian officers and ratings have served the world maritime profession diligently and India is proud to have emerged as a major supplier of seafarers to the world merchant shipping. Indian officers and ratings are known to be amongst the best in the world and from a share of around 2% in the year 2000, presently Indian seafarers constitute about 11% of total worldwide seafarers. This growth has been possible because of the maritime education and training infrastructure of our country.
(d) In recent years, the ships have become technologically very much advanced and the knowledge and skill sets required to man and operate these complex ships have accordingly undergone radical changes. Shipping is now a knowledge based and skill driven industry more than ever before, making the role played by training institutes, administration and shipping companies in grooming these seafarers fit for the job, very significant.

(e) Piracy and criminalisation of seafarers have made the maritime industry less of a choice for best of the Indian talent to opt as a career. Further, most of the seafarers, more so the officers are choosing to quit sailing and find alternate employment ashore within 6-8 years of their sea career as against 15-20 years in the 90s. This has created an acute shortage of senior level officers. Although the size of the world fleet has increased considerably, the supply of quality seafarers has not increased proportionately. Shorter career span of seafarers have made this challenge even more acute as shown in Fig 2.5 above.

(f) The Ministry of Shipping has taken a number of steps to meet this challenge. Presently, there are 131 approved Maritime Training Institutes in India, imparting pre-sea and post-sea training to maritime personnel (Directorate General of Shipping).

(g) Indian Maritime University (IMU) has also been established as a central University under Ministry of Shipping to promote maritime education, training and research and also facilitate other emerging areas of maritime studies like oceanography, maritime history, maritime law, logistics and supply chain management and related areas as shown in Fig 2.6.

(h) Maritime industry has very high global manifestation in all aspects of its operations, and there is an urgent and compelling need to augment pool of high quality seafarers in right quantities, at the right time. Maritime education, training and research should now be aimed at improving the quality of maritime education and skill sets through high levels of standardisation across India.

(i) Significant increase is predicted in the demand for Indian officers in the future, especially in specialised sectors of LNG, LPG, Very Large Crude Carrier (VLCCs), and oil & chemical tankers. While China may continue to train more number of seafarers, the phenomenal growth of Chinese shipping industry is unlikely to allow too many officers for global supply. Therefore, India and Philippines will continue to be major crew supplying nations in Asia in the foreseeable future and policies need to be framed accordingly.
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6. Compiled from data available from manpower reports of International Chamber of Shipping (ICS) and Baltic and International Maritime Council (BIMCO)

7. Compiled from data available from manpower reports of International Chamber of Shipping (ICS) and Baltic and International Maritime Council (BIMCO)

8. Compiled from records available with Directorate General of Shipping (DGS)
Almost 90% of global trade by weight is done through commercial shipping in a cost and energy efficient way as compared to the other modes of transport. The regulatory framework for international shipping is prescribed by the International Maritime Organization (IMO); the industry's regulating body based in London. Key environmental regulations coming into force this decade are emissions of greenhouse gases (GHG), in particular carbon dioxide (CO\textsubscript{2}), sulphur oxides (SO\textsubscript{x}), nitrous oxides (NO\textsubscript{x}), particulate matter (PM) as well as ballast water management. Complying with these regulations will have significant technological, financial and operational implications for the shipping industry.

3.1 CO\textsubscript{2} EMISSIONS REDUCTION MEASURES

The 20\textsuperscript{th} century has been an era of rapid industrialisation. Due to exponentially increased industrial activities and burning of fossil fuels, CO\textsubscript{2} concentration in the earth's atmosphere has been rising consistently over the past several decades, thus contributing to global warming and climate change. Greenhouse gases such as CO\textsubscript{2} are the primary contributor to the anthropogenic warming of the atmosphere, as is evident from Fig 3.1 indicating the percentage composition of GHG.

According to Assessment Report (AR 5) of Intergovernmental Panel on Climate Change (IPCC), an increase in atmospheric CO\textsubscript{2} concentration to 450 ppm level will lead to a 2\textdegree Celsius rise in global average temperature. In 2015 Paris Agreement it was agreed by all parties to hold the global average temperature to well below 2\textdegree C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5\textdegree C. Now, all efforts are being made by international regimes worldwide to restrict CO\textsubscript{2} concentration in the atmosphere to 450 ppm level. According to IPCC forecasts, as shown in Fig 3.2, the ‘Business As Usual’ use of fossil fuel will lead to considerably high CO\textsubscript{2} concentration by the end of the 21\textsuperscript{st} century. Therefore, in order to limit the atmospheric concentration of CO\textsubscript{2} to the

FIG 3.1: BREAKUP OF MAJOR GHG EMISSIONS [GLOBAL DATA][1]
maximum limit of 450 ppm, drastic reduction of CO₂ emission is a must.

Shipping is no exception. CO₂ emission from ships’ engines by way of exhaust gases contributes significantly to the harmful air pollution and has been growing steadily over the years, consistent with the growth of international trade (as shown in fig 3.2 above). According to the IMO’s second Green House Gas (GHG) Study report 2009, ships are responsible for some 3.3% of annual global CO₂ emission (2.7% from ships on
international trade and 0.6% from domestic and fishing vessels). Fig 3.3 shows the contribution of shipping to global CO₂ emissions.

The Third IMO Green House Gas Study 2014 represents the most detailed and comprehensive global inventory of shipping emissions to date. As per the report, for the period 2007-2012, on an average total shipping accounted for CO₂ emissions at 3.1% as against 3.3% and International Shipping accounted for 2.6% as against 2.7% slightly lower as reported by Second IMO GHG study 2009.

Economic pressures and international legislation now require a sensitive use of energy resources and a reduction of the associated emissions. IMO has been under a lot of pressure from the international community to implement strategies for reduction and prevention of environment pollution from shipping.

Sustainable shipping with low carbon growth is the need of the 21st century. Sustainability is a development process that creates harmony with the natural environment and calls for measures to secure the well-being of current and future generations, while maintaining the growth of the industries at the same time. A three pronged approach has been taken up by the IMO, which is aimed at providing substantial improvements to ship energy efficiency and reduction of GHG emissions from water transport. These three measures are:

### Concept of Energy Efficiency Design Index (EEDI)

EEDI has been introduced. This is a mandatory measure and is intended to stimulate improved energy efficiency in the new ships, at the design stage itself.

The concept of Ship Energy Efficiency Management Plan (SEEMP) is also a mandatory measure and is intended to stimulate improved energy efficiency in existing as well as new ships by optimising energy consumption in a variety of operational conditions encountered through the life-cycle of a ship.

This is to supplement the technical and operational measures and places a price on GHG emissions. It is still being deliberated at IMO and may include emission trading, emission related levies – charges and taxes, and emission offsetting in other sectors.

#### 3.1.1 Energy Efficiency Design Index (EEDI)

It is an index quantifying the amount of CO₂ that a new ship should emit in relation to the goods transported. EEDI creates a common metric (system of measurement) to measure and improve new ship efficiency. The metric is calculated as the rate of CO₂ emissions from a ship per transport work performed by the ship. CO₂ emissions are directly related to energy efficiency and are calculated as fuel consumption multiplied by a fuel carbon factor. Transport work is calculated as a function of the cargo capacity of the ship and the designed ship speed.

The EEDI is calculated by using the fundamental formula:

$$EEDI = \frac{\text{Environmental Cost Benefit for society}}{\text{Quantity of CO}_2 \text{ emissions}} = \frac{\text{Transport work (tonne-mile of cargo moved)}}{\text{P . SFC . C}_f \cdot \text{DWT . Vref}}$$

Where, P = 75% of the rated installed shaft power; SFC = the specific fuel consumption of the engine; $C_f$ = Fuel carbon factor (CO₂ emission rate based on fuel type); DWT = Ship’s deadweight tonnage and Vref = Vessel’s speed at designed load.

The calculated EEDI (attained EEDI) based on designed specifications and sea trials of new ships will have to be below a reference value (required EEDI) that is based on a regression of EEDI values from existing ships built between the years 2000 to 2010 (reference line). The EEDI regulation applies to new cargo ships greater than 400 Gross Tonnes (GT) and varies with ship type, size and function. The categories of ships covered include oil and gas tankers, bulk carriers, general cargo ships, refrigerated cargo carriers, and container ships. Together, the included ship categories, account for 72% of CO₂ emissions from the new world fleet.

The regulation does not currently apply to passenger, mixed-use vessels (ferries, roll-on roll-off (Ro-Ro) ships or vehicle carriers and cruise ships), and other specialty ships for which deadweight tonnage is not an adequate representation of transportation capacity. It also does not apply to ships fitted with non-standard propulsion systems, such as diesel-electric, turbine or hybrid propulsion systems. These may be included by IMO at a later stage.
From January 1, 2013, following an initial two year phase zero, the CO$_2$ reduction level for the first phase is set to 10% and will be tightened every five years to keep pace with the technological developments towards efficiency enhancements and CO$_2$ reduction measures. Reduction rates have been established until the period 2025-2030, when 30% reductions are mandated as shown in Table 3.1.

3.1.2 Ship Energy Efficiency Management Plan (SEEMP)

While the Energy Efficiency Design Index (EEDI) addresses the energy efficiency of only new build ships at the design stage, Ship Energy Efficiency Management Plan (SEEMP) addresses the energy efficiency of all ships i.e. new build as well as existing ships.

The main objective of SEEMP is to establish a management tool incorporating best practices for fuel efficient ship operation, thereby minimising wastage of energy in all possible areas, improving energy efficiency of ship operation and thus reducing CO$_2$ emissions from the vessel. It is a ship specific system to be used by ship operators in order to enhance the energy efficiency and emissions performance of their ships by applying identified technical and operational measures to improve fuel efficiency.

Shipboard and shore-based management teams are expected to explore all practical and cost effective avenues for implementing SEEMP measures either individually or cumulatively, while giving due consideration to safety and security issues. Measures to improve energy efficiency of existing ships could be:

(i) **Operational in nature** – Engine operational performance and condition optimization, improved voyage planning and execution, weather routing, speed optimization, trim and draft optimisation, more frequent hull and propeller cleaning etc.

(ii) **Technical in nature** – Fitment of appendages for improvement of ship’s propulsion efficiency, waste heat recovery systems, a new propeller, or application of low friction advanced hull coating etc.

The SEEMP urges the ship owners and operators at each stage of the plan to consider new technologies and practices, when seeking to optimise the performance of a ship.

3.1.3 Benefits from implementation of EEDI & SEEMP

The EEDI for new ships is the most important technical measure and it aims at promoting the use of more energy efficient (less polluting) equipment and engines. It is expected to stimulate continued innovation and technical development of all the components influencing the fuel efficiency of a ship from its design phase. It is a non-prescriptive, performance based mechanism that leaves the choice of technologies to be used in a specific ship design to the industry. As long as the required energy efficiency level is attained, ship designers and builders are free to use the most cost-efficient solutions for the ship in order to comply with the regulations.

Similarly SEEMP aims at making ship operations more energy efficient. An energy efficient

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**TABLE 3.1: EEDI REDUCTION FACTORS, CUT-OFF LIMITS AND IMPLEMENTATION PHASES. (IMO)[4]**

<table>
<thead>
<tr>
<th>TYPE OF SHIPS</th>
<th>SIZE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk Carriers</td>
<td>&gt;20,000 Dwt</td>
</tr>
<tr>
<td>Gas Tankers</td>
<td>&gt;10,000 Dwt</td>
</tr>
<tr>
<td>Tanker and combination carrier</td>
<td>&gt;20,000 Dwt</td>
</tr>
<tr>
<td>Container Ships</td>
<td>&gt;15,000 Dwt</td>
</tr>
<tr>
<td>General cargo ships</td>
<td>&gt;15,000 Dwt</td>
</tr>
<tr>
<td>Refrigerated cargo carriers</td>
<td>&gt;5,000 Dwt</td>
</tr>
</tbody>
</table>

**EEDI REDUCTION FACTORS FOR DIFFERENT PHASES**

<table>
<thead>
<tr>
<th>Phase 0 1st Jan 2013-31st Dec 2014</th>
<th>0% N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 1 1st Jan 2015-31st Dec 2019</td>
<td>10% 0-10%*</td>
</tr>
<tr>
<td>Phase 2 1st Jan 2020-31st Dec 2024</td>
<td>20% 0-20%*</td>
</tr>
<tr>
<td>Phase 3 1st Jan 2025 onwards</td>
<td>30% 0-30%*</td>
</tr>
</tbody>
</table>

*The reduction factor is to be linearly interpolated between the two values depending on the vessel size. The lower value of the reduction factor is to be applied to the smaller ship size.
vessel will always prove to be a “cleaner” vessel compared with a ship not optimised for energy consumption. It is indicated that SEEMP measures (mainly operational) will have an effect mostly in the medium term (e.g. 2020), whereas the EEDI measures (technical) should have significant impact in the long run (e.g. 2030-2050) as fleet renewal takes place and new technologies are adopted.

When these programmes are fully phased in, ships will be 30% more energy efficient than they are today. These energy efficiency improvement measures are different from other emission abatement technologies as they fulfil two purposes – they reduce fuel oil consumption and not emission directly, and they are (potentially) cost effective.

It may be noted that while the yield of individual measures may be small, the collective effect of these measures on the environment would be significant. More efficient ships will also emit lower amounts of other pollutants such as NO\textsubscript{x}, SO\textsubscript{x}, and particulate matter (PM). Emissions of CO\textsubscript{2}, which are directly related to fuel oil consumption, will be reduced by 30% per ship compared to typical ships operating today (Fig 3.4). Reduction in these air emissions will restrict global warming and climate change, thereby, benefiting human-health and the environment, including benefits from reduced acid deposition in our oceans.

3.2 SO\textsubscript{x} EMISSION REDUCTION MEASURES
Based on existing marine engine technology and expected technology developments, ship-owners currently have two main choices for SO\textsubscript{x} emissions reduction – either to install an exhaust gas scrubber or to switch over to low sulphur fuel, including LNG.

The exhaust gas scrubber allows the ship to use cheaper, readily available high sulphur fuel. Besides removing nearly all sulphur from the engine exhaust, a scrubber also removes a large part of soot and particulate matter. However, the system takes up space, and requires significant investment cost and additional energy for its operation. Installations are generally bulky and require alterations on-board ships, such as additional tanks, pipes, pumps and a wash-water treatment system. Since these require additional energy for their operation, power consumption is increased by some percentage, thereby increasing the total CO\textsubscript{2} emissions.

3.3 NO\textsubscript{x} EMISSION REDUCTION MEASURES
Ship-owners currently have the following choices for NO\textsubscript{x} emissions reduction:
3.4 BALLAST WATER TREATMENT MEASURES

There have been many instances, where alien species / organisms carried with ship's ballast water, when discharged in new environment, have caused invasion of the new environment bringing about dramatic shift in food chain, disease outbreaks and extinction of indigenous species. In response to this, IMO has come out with ballast water management convention with a set of regulations that severely limit the amount of organisms permitted to be carried in ship's ballast water.

Many ballast water treatment systems are now available in the market. All systems, however, have relatively limited operational experience and come with an inherent technological uncertainty. The choice of technology used will depend on the vessel type, trading pattern, vessel size and design. However, all ballast water management technologies involve a filtration process, which separates particles from the water flow using membrane and cyclones.

The filtration process is followed by mechanical/physical processes or active substances. The mechanical/physical processes can include cavitations, UV lighting, heat, vacuum, oxygen stripping or acoustic treatment. The physical process is often the main mechanism of ballast water treatment system and may have large power demand. Active/chemical substances are added to the ballast water to terminate the living organisms and for disinfection purposes and can include the use of ozone, sea water electrolysis, additives or a catalyst.

3.5 CONCLUSION

India is a party to several International conventions, and in order to maintain tradability of Indian registered ships in International waters, Indian ships will have to adopt the above measures for compliance. The decision on whether or not to invest in a new ship and what kind of technology the new ship should have is in the hands of the ship owner. The ship owners’ decisions will be influenced by both commercial and regulatory factors.

REFERENCES


4. IMO, Marine Environment protection committee 63rd session, p. 4

In order to be able to comply with upcoming stringent regulations, the shipping industry will have to adapt to new technologies over the next decades. For each regulation, a ship owner will have multiple feasible technologies to choose from. Similarly, fuel cost will also have a strong impact on adaptation of new technology. The regulatory shift towards low sulphur fuel is one of the developments in the industry that will have the largest impact in terms of shipping cost and operations. Following the new regulations, low sulphur fuel will be in great demand, increasing its cost which in turn may lead to a higher demand for alternative fuels.

4.1 Engineering Aspects

As is evident, measures adopted by IMO are aimed at spurring development of energy efficient ships through application of innovative tools and concepts both in ship design as well as in its operation. In order to achieve the objective of a ship optimized for energy consumption, an analysis of the causes for the use of energy, when the ship is in service, has to be undertaken.

As shown, only a fraction of the energy obtained through combustion of fuel in a ship’s main engine, actually ends up generating propulsion thrust. The bottom bar in this diagram represents the energy input to the main engine from combustion of fuel. In this case, 43% of the fuel energy is converted to shaft power while the remaining 57% energy is lost by way of exhaust gases and heat loss. Due to further losses in the propeller and transmission, only 28% of the energy from the fuel that is fed to the main engine generates propulsion thrust in this example.

The majority of this remaining 28% is spent in overcoming hull friction, while the rest is spent in overcoming air resistance, as residual losses, as weather resistance and for wave generation.

**Figure 4.1: Energy Balance of a Typical Small Cargo Ship[1]**
In addition to this, there is fuel consumption for operation of auxiliary engines that supplies power to the auxiliary machineries and to the lighting loads. Ships other than the case shown will have similar type of losses, although, the percentages may differ.

It can be clearly deduced from the above analysis that most important causes for energy consumption on board a ship are due to hydrodynamic effects, which comprise of energy spent for propulsion and in overcoming ship's resistance (inclusive of wave-making resistance and hull friction i.e. viscous drag). Other than for passenger ships where hotel loads and other auxiliary systems are large contributors, cargo ships use up to 90% of all practically available energy for propulsion, excluding all internal losses in a combustion engine.

Consequently, a focus on low ship resistance and improved propulsive efficiency through hydrodynamic optimization, promises the largest gain. Besides this, optimization of energy systems together with use of promising technologies for energy generation from alternative fuels or non-fossil renewable sources on-board a ship lead the way ahead for future low energy and low emission i.e. green shipping.

4.2 TECHNOLOGIES WITH POTENTIAL FOR ENERGY SAVING/ EMISSION REDUCTION

Technology options in respect of above mentioned aspects that are technically achievable from an engineering point of view and have the potential to significantly improve energy efficiency and reduce emissions from ships in the short, medium and long term are discussed below:

4.2.1. Hull and propeller

A ship's hull and propeller design contributes significantly to her overall hydrodynamic efficiency. Discussed below are the measures that have the potential for improvement of hull and propeller efficiency through hydrodynamic optimization:

(a) Optimized hull dimensions and form: Major Hull dimensions of a ship are determined at the design stage (Fig 4.2). Careful hull design can significantly reduce the energy spent towards wave resistance of a ship. The hull dimensions should meet the specific requirements of the ship such as the shipping routes (port and canal restrictions), the type of ship, the deadweight tonnage and the ship speed. The block coefficient and slenderness ratio are the most important non-dimensional main parameters, which influence the form related wave-making resistance of a ship. Studies have shown that based on the typical ship design standard today, the EEDI may be decreased by 5-10% by selecting more favourable hull proportions (i.e. a lower block coefficient and a higher slenderness ratio), even without changing the speed or introducing any new technical measure. Thus optimization of hull dimensions and form are important and crucial for ship energy efficiency.

(b) Hull Coating: Apart from wave-making resistance, viscous drag plays a very important role in overall hydrodynamic efficiency of a ship. The main parameter affecting viscous drag of a ship is surface roughness of its hull. The energy spent in overcoming viscous drag of a ship can be significantly reduced by enhancing the smoothness of hull through initial production quality, surface preparation and maintaining it free of fouling during vessel's operation using advanced hull coatings. Such low-surface energy (LSE) coatings create non-stick surfaces similar to those known in Teflon coated pans. By reducing the hull roughness and inhibiting marine fouling, LSE coatings have
the potential to reduce fuel consumption and consequently emissions.

(c) Hull air lubrication system: Air lubrication has attracted some attention in recent years as it has the potential to significantly reduce viscous drag of a ship. The principle of operation is that a film of air on part of the hull reduces friction and in turn fuel consumption. The basic concepts include:

• Air bubbles lubrication system: This system is based on the powered injection of air beneath the ship. Several small holes on the hull’s bottom are used for injection of micro air bubbles into the flow stream. By interfering with the generation of vortices, the transition to the highly dissipative turbulent flow regime, which typically occurs around the hull, is delayed. This helps in reduction of viscous drag due to lower friction forces associated with laminar flow as compared with turbulent flow. However, the concept is not without problems. Uncertainties in the physical mechanisms and the scaling and technical feasibility of this system need to be resolved. In particular, the potentially negative interactions of the dispersed bubbles with the propeller must be eliminated before use of the concept on board ships is popularized.

• Air cavity lubrication system: In air cavity lubrication system, large indentations are opened on the hull’s bottom. An air injection system delivers air to the cavity through a system of automated compressors and valves. A control system monitors the volume and pressure of the air and establishes and maintains an optimal and continuous air cavity. The steel-seawater interface is thus replaced by a more slippery air-seawater interface, effectively reducing the hull’s wetted surface area and thereby the viscous drag. The technology is still under trials. Air injection system requires about 1~3% of additional power. A decrease in fuel consumption of around 15% is claimed. Negative side effects include the generation of a destabilizing free surface under the hull and loss of energy both due to formation of gravity waves on this free surface and by dispersion of bubbles into the propeller inflow.

4.2.2 Use of hybrid lightweight material for ship construction

By reducing the weight of a ship’s hull, consumption of fuel and therefore emissions can be reduced. Steel can be replaced by lighter weight alternatives in non-structural elements or by lower weight high-tensile steel. At present, lightweight materials such as aluminium, carbon fibre or glass-fibre sandwich constructions are being mainly used for high-speed crafts. Hybrid materials can be formed from multiple layers of metal sheets and piles of polymer composite laminates. Fibre-metal laminates combine the qualities of

FIG 4.3: AIR CAVITY LUBRICATION SYSTEM[3]
metals (high impact resistance, durability, flexible manufacturing) with those of composites (high strength and stiffness to weight ratio, good resistance to fatigue and corrosion). The metals can be of either aluminium or steel plates, whereas the polymer core can be reinforced with carbon or glass fibres. Successful application of these materials in the aeronautical industry and in specialized ships provides an opening for introducing these materials into main shipping also. However, widespread adoption in the near future is unlikely, the main constraints being high costs, manufacturing and recycling challenges, and fire resistance issues.

4.2.3 Optimization of propeller-hull interface, flow devices and improvement of propulsion efficiency

Redesigning hull, rudder and propeller with changes to ship’s aft body can improve the interaction between these three elements and improve propulsion and hydrodynamic efficiency. Energy balance of a typical propeller is shown in the following figure:

As can be seen, unfavourable wake flow from the hull into the propeller as well as energy losses from propeller rotation reduce the potential thrust that can be gained from a propeller to about 60%. Some of the technologies that have the potential to improve ship’s propulsion efficiency such as appendages and supplements to propeller systems have been discussed in the following paragraphs. Most of the technologies described, aim to recover part of the 40% losses.

4.2.4 Ducted Propeller

Efficiency of propulsion can be further increased by fitting auxiliary devices such as Wake equalizing duct or a Mewis duct. Ducted (shrouded) propellers have some potential for very large tankers. They become attractive with high thrust loading – a large mass moving at low speed – and since tanker speed is sensibly constant across the size range, then for very large units such as Ultra Large Crude Carriers (ULCC) ducts may show some benefits.

4.2.5 Pre and post-swirl devices

Most ships lose a substantial amount of energy through rotation of the propeller, imparting rotational rather than axial momentum on the water. A large number of devices have been proposed to recover some of this energy. These can be categorized into pre-swirl (upstream of the propeller) and post-swirl (downstream of the propeller) devices. They are simple, do not
rotate (so without bearings) and can reduce the rotational losses generated by the propeller. Rotational losses are generally between 5~7%, so the potential saving is attractive and therefore the technology is promising for future development.

4.2.6 Podded Propellers
Podded propellers have higher efficiencies because the propellers operate in faster, less disturbed water outside the boundary layer. There is also a saving resulting from being able to reshape the aft end of the hull and reduce the overall resistance of the ship. Pods also have greater flexibility for the power train and provide efficient manoeuvrability in port. However, there have been some high-profile bearing problems reported following the application of pods to the cruise ship market and it is still an evolving technology.

4.2.7 Coaxial contra-rotating propellers
In a contra-rotating configuration two propellers face each other; rotating in the opposite direction, with the aft propeller recovering the rotational energy in the slipstream from the forward propeller. Theoretically about 10-12% improvement in propulsive efficiency is achievable. However, there are mechanical difficulties of rotating shafts at different speeds in opposite directions, one inside the other; and the bearing and lubrication problems that arise as a consequence. Some solutions have been found, the best of which appears to be mounting a pod on the rudder horn separate from the main propeller; but there are very few ships in service with this type of propulsion and it is not yet a mature technology to be applied to large full form ships. The complexity is quite high with cost and risk but with promise.

4.2.8 Design and optimization with computational fluid dynamics (CFD)
Traditionally hull forms and propeller designs have been optimized by model testing which was done relatively late in the design process and changes required if any were very costly. Presently, the use of CFD speeds up that process. CFD is based on numerical methods and algorithms and is used to analyse and solve complex problems involving fluids and gases. It is regarded as a reliable and accurate tool for calculation of the hull resistance of a ship at a certain speed in order to find the optimum design in the early design phase. In that phase many important overall design considerations and decisions are made and the propulsion system is selected. Use of advanced CFD technology can solve a long list of complex problems e.g., resistance, noise from propellers, and investigate the interaction between propeller, hull and rudder. The impact of waves on the hull, superstructures or offshore structures can also be investigated. Therefore, use of advanced CFD technology in the early design phase where it is easier and more cost effective, may prove to be of great help and should be encouraged for
optimization of hull dimensions and form of a new vessel.

4.2.9 Optimization of energy systems
Energy systems that have the energy saving potential and which ultimately lead to emission reduction are discussed below in the following paragraphs:

(a) Engine efficiency improvement: Engine efficiency in its whole range of operation, may be improved in various ways e.g. through design change, de-rating, long-stroke, electronic injection, common rail injection, two stage turbo-charging, variable geometry turbo-charging etc. However, the engine development is currently dominated by the upcoming requirements of IMO of reducing NOx – emissions. This, inherently, will reduce fuel efficiency, because of lower combustion temperatures and increased back pressure as a result of exhaust gas cleaning systems. Part of it, if not all potential improvements, may be consumed to compensate for the effects of NOx – emission control. While a further enhancement of fuel efficiency may be possible through development of diesel engine technology, impending legislation suggests that no overall contribution of the engine sector to reduce fuel consumption and GHG – emissions from shipping may be possible.

(b) Main Engine Tuning: In main engine tuning, the most commonly used load ranges have to be determined and then the main engine is optimized for operation at that load. This measure requires a different engine mapping for various engine loads and speeds. Further, specific changes in the engine hardware such as changing the cam profile results in improved efficiency. The fuel injection as well as ignition timing can be varied by the use of an electronic control units and sensors for optimum engine performance. This measure can reduce overall fuel consumption although there may be a fuel use penalty under seldom – used full load operations.

(c) Waste heat recovery: Approximately 27% of energy produced through combustion of fuel in main engine is lost in the exhaust heat. The basic premise of the waste heat recovery process is to redirect and to reuse this energy that would be otherwise wasted to the atmosphere or the engine cooling systems. With a waste heat recovery (WHR) system, thermal heat losses from the exhaust gases of the engines can be either utilized for driving turbines to produce electricity or for additional propulsion through use of a shaft motor leading to less fuel consumption by the engines. The amount of heat that may be recovered from the exhaust gases is governed by the type of engines used, the exhaust gas temperature (allowable outlet temperature of exhaust gas heat exchanger being restricted by dew point of acid formation) and the sulphur content in the fuel.

It may not be possible to retrofit such systems into existing ships. However, shipbuilders need to be encouraged to incorporate such new technologies while constructing new ships at the design stage itself.

4.2.10 Reducing on board power demand (auxiliary system and hotel loads)
There are many different ways by which electric power demand on board ships can be reduced. Some of these options are listed below:

- By encouraging use of lighting appliances that consume less electricity and are heat efficient.
- By using energy efficient heating, ventilation and air-conditioning.
- By using pumps and fans at variable speed as per actual needs.
- Use of variable speed electric motors for control of rotating flow machineries, has the potential to significantly reduce energy consumption.
- In pumping applications with variable flow rate requirements, variable frequency drives (VFD) provide an efficient control alternative to throttling (valve control) or bypass methods.
- By using frequency controlled variable speed pumps instead of fixed rpm pumps (for cooling water and other systems with high utilization rate) substantial reduction in energy consumption for the pumps can be achieved.

4.2.11 Energy generation from alternative fuels
Fossil fuel is likely to prevail as the dominant source of primary energy for the shipping industry as of now and in the near future because of its large-scale availability and widespread distribution network. However, environmental/financial
concerns and dwindling fossil fuel reserves are paving way for the use of alternative fuels such as bio-fuels, liquid natural gas (LNG), Hydrogen for fuel cell, solar energy or nuclear fuel for energy generation.

(a) Bio-fuel as an alternative fuel:
Bio-fuel, as the name suggests, is fuel oil derived from plants i.e. vegetable oil. The concept of using vegetable oil as fuel dates back to 1895 when Rudolf Diesel developed the first diesel engine to run on groundnut oil. It is a realistic and sustainable renewable energy source with the potential of considerable decrease in lifecycle CO₂ emissions. In comparison with fossil fuels, it does not contribute to SO₂ emissions since it does not contain sulphur. Particulate matter emissions are also reduced but NOₓ emissions are slightly increased. It is biodegradable and is therefore safer to handle and transport.

In principle, existing diesel engines can run on bio-fuel blends. Therefore, use of bio-fuels on board ships is technically possible. The most promising bio-fuels for ships are biodiesel and crude plant oil. Biodiesel is most suitable for replacing marine distillate, while plant oil is suitable for replacing residual fuels. One of the most promising developments is the use of algae to produce bio-fuels with molecular structure similar to petroleum and refined hydrocarbon products in use today, offering the potential for manufacturing a range of fuels including gasoline, diesel fuels and jet fuels with the same specification.

There are, however, various unresolved problems. These include fuel instability, corrosion, susceptibility to microbial growth, adverse effects on piping and instrumentation, and poor cold flow properties. Although these technical challenges could be resolved in future, widespread use of bio-fuels in shipping will depend on price, other incentives and availability in sufficient volumes. Breakthroughs in production methods and imposition of new regulations may have a significant impact. In Indian context, bio-fuels can bring about self-sufficiency in the field of energy. It is important for not only saving our economy which is so much dependent on oil imports but also for keeping our environment less polluted. The most significant point about bio-fuels is that it is a renewable source of energy. Development and promotion of such renewable sources of energy, to partially offset the energy import and dependence on oil/coal to the extent possible, should therefore be one of the most important goals.

(b) Liquefied natural gas (LNG) as an alternative fuel:
Natural gas is well established as a major contributor to the world’s energy needs. But as far as shipping industry is concerned, its use as an alternative to residual fuel oil has remained limited to LNG carriers and for short sea shipping (SSS) or in other words coastal shipping, inshore and inland shipping in some regions of the world such as in some countries of European Union (EU) and United States of America (USA) with established LNG bunkering infrastructure. However, in the present circumstances, the choice of LNG as an alternative fuel for maritime industry surely is a viable option for the following reasons:

The use of LNG as fuel on board ships can support long term emission reduction of GHGs like CO₂ by 20%, SO₂ by 80%, particulate matter (PM) by 73%. So it is a cleaner source of energy and therefore the most suitable fuel option for emission reduction and environmental pollution prevention. The carbon content of LNG (2.75) is least as compared to diesel oil (3.20) and residual fuel oil (3.11). Therefore use of LNG has the potential to improve EEDI of ship. The last thirty years have seen a shift in the global energy fuel mix towards an increased role for natural gas. In the last five years global LNG production has increased by almost 40% and the number of countries exporting and importing LNG has been growing steadily. This trend is likely to continue in the foreseeable future.

Ships trading in designated emission control areas have to use on board fuel oil with a sulphur content of no more than 0.10% from 1st January 2015, against the limit of 1.00% in effect up until 31st December 2014. The emission control areas established under MARPOL Annex VI for SO₂ are: the Baltic sea area, the North Sea area, the North American area (covering designated coastal areas of the United States and Canada), and the United States Caribbean Sea area (arising Puerto Rico and United States Virgin Islands). It is certain that stringent air pollution prevention norms will be enforced around the globe sooner. With the reduction of sulphur percentage, production cost of fuel at the refineries increases considerably. Under the circumstances the pricing and availability of LNG as compared to low sulphur fuel may become attractive enough for ship operators to prefer use of LNG on board ships.

To meet the emission reduction requirements, there are only two realistic alternatives: exhaust
FIG 4.10: LOCATION OF LNG STORAGE TERMINALS IN INDIA [10]

- **DABHOL**
  - Owner: Ratnagiri Gas and Power Ltd
  - Capacity: 5 mmtpa
  - Supplier: Awaiting source supply Tie-ups

- **KOCHI**
  - Owner: Petronet LNG Ltd
  - Capacity: 5 mmtpa
  - Supplier: Western Australia-based Gorgon Gas

- **MUNDRA**
  - Owners: GSPC, Adani
  - Capacity: 5 mmtpa

- **ENNORE**
  - Owners: IOCL, Petronas LNG Ltd
  - Capacity: 2.5 mmtpa
  - Supplier: Awaiting supply Tie-ups

**CONSTRUCTED**

- **CHARA**
  - Owner: Shapoorji Pallonji

- **DHAMRA**
  - Owner: Tata Steel, L&T

- **DIGHI**
  - Owner: Hiranandani

- **JAIGARH**
  - Owner: JSW

**PLANNING STAGE**

- **GANGAViewModel**
  - Owner: Petronet LNG Ltd
  - Capacity: 5 mmtpa
  - Supplier: Not known

- **HAZIRA**
  - Owner: Shell 74%, Total 26%
  - Capacity: 3.5 mmtpa
  - Supplier: Mostly spot buying

- **DAHEJ**
  - Owner: Petronet LNG Ltd
  - Capacity: 10 mmtpa
  - Supplier: RasGas, Qatar

**SMALL TERMINALS**

- **DHAMRA**
  - Owner: Tata Steel, L&T

- **DIGHI**
  - Owner: Hiranandani

- **JAIGARH**
  - Owner: JSW

**UNDER CONSTRUCTION**

- **HAZIRA**
  - Owner: Shell 74%, Total 26%
  - Capacity: 3.5 mmtpa
  - Supplier: Mostly spot buying

- **DAHEJ**
  - Owner: Petronet LNG Ltd
  - Capacity: 10 mmtpa
  - Supplier: RasGas, Qatar
gas treatment or use of natural gas. Exhaust gas treatment can be utilized but the space and maintenance requirements are daunting. The ship operators view installing exhaust gas treatment systems as a last resort when nothing else is possible. LNG, therefore, becomes the preferred choice.

Presently gas engine dual-fuel (DF) technology is being applied for Marine applications. Modern DF engines are reliable and can burn gas and oil at any ratio depending upon availability and cost.

- **Challenges for LNG:**

The biggest challenge preventing widespread use of LNG as fuel in international shipping is lack of worldwide availability of bunkering infrastructure to ensure supply of LNG of appropriate & consistent quality.

Presently the cost of installing a DF engine plus fuel tanks is estimated to be around twice that of a conventional diesel engine and its fuel tanks.

LNG is predominantly methane, which is a substantially worse greenhouse gas than CO₂. Probability of methane slip i.e. release of unburned natural gas either through the engine exhaust or during bunkering or uses otherwise is a cause of concern and needs to be addressed as the GHG effect of 1 Kg of methane discharged to the atmosphere is the equivalent of 21 Kg of CO₂ being emitted.

From the foregoing, it can be inferred that LNG as fuel is a viable option for international shipping provided bunkering infrastructure becomes available globally. Short sea shipping is the most obvious area to start with. Price difference between fuel oil and LNG will be the deciding factor for LNG to appear soon as an alternative fuel in international shipping.

IMO has adopted a global regulation for gas-fuelled ships on June 11, 2015, “The International Code of Safety for ships using Gases or other Low-flashpoint Fuels (IGF Code)”. When it enters into force on January 1, 2017, it will apply to all vessels above 500 gross tonnage that install low flash point fuel systems. Implementation of IGF Code will facilitate wider use of LNG as fuel on board ships trading in International waters.

Presently, India is the 4th largest importer and 13th largest consumer of LNG in the world. As can be seen in the figure given below, opportunities for developing bunkering infrastructure is available around the coastline which needs to be augmented / developed for short sea shipping. Development of coastal shipping will definitely get a boost once the LNG bunkering infrastructure is available around the coastline since short sea shipping will provide a cheaper and cleaner means of transporting goods than by road transport. Development of coastal shipping in India must be treated as a national priority as road transport costs are high as compared to shipping and gets added to the cost of the product, rendering them uncompetitive internationally and expensive nationally.

(c) Nuclear energy as an alternative fuel: Nuclear power has been there for quite some time powering vessels at sea but mostly these have been for naval applications. Following are some facts about marine application of nuclear power:

1. Nuclear power is particularly suitable for vessels that need to be at sea for long periods without refuelling or for powerful submarine propulsion.
2. Some 140 vessels have been powered by more than 180 small nuclear reactors and more than 12000 reactor years of marine operations have been accumulated. Most of these vessels are submarines, but icebreakers and aircraft carriers are also included.
3. Nuclear ships are currently the responsibility of their owner countries but none are involved in International Trade.

- **Civil applications:** Nuclear propulsion has proven technically and economically essential in the Russian Arctic where operating conditions are beyond the capability of conventional icebreakers. The power levels required for breaking ice up to 3 meters thick, coupled with refuelling difficulties for other types of vessels, require nuclear propulsion.

- **Future prospects:** With increasing attention being given to GHG emissions arising from burning fossil fuels for international marine transport and the excellent safety record of
nuclear powered ships, it is quite conceivable that renewed attention will be given to marine nuclear powered ships. Babcock International’s marine division completed a study on developing a nuclear powered LNG tanker, which required considerable power for auxiliaries as well as for propulsion. The study indicated that particular routes and cargoes lent themselves well to the nuclear propulsion option, and that technological advances in reactor design and manufacturing had made the option more appealing. Lloyd’s Register, a classification society study carried out in 2010 expects to see nuclear ships on specific trade routes sooner than many people currently anticipate. Nuclear power seems most immediately promising for the following:

1. Large bulk carriers that continuously operate on fixed routes between dedicated ports.
2. Cruise liners, which have very high hotel loads like a small town. A nuclear powered unit could give base-load and charges batteries, with a smaller diesel unit supplying at the peaks.
3. Nuclear tugs, to take conventional ships across oceans.
4. Some kind of bulk shipping, where speed is essential.

- **Challenges for Nuclear Energy:** There are some major challenges that need to be addressed before nuclear powered merchant ships can see light of the day. These are shown below:

As far as India is concerned, the country is already having the expertise of erection and operation of nuclear power plants. Also technology for construction of nuclear submarines is already there with the launching of first nuclear submarine, “Arihant” in the year 2009 and now of,“Aridhaman”. India must be ready with marine nuclear technology for its use in international shipping, in case, there is change in public perception or for some specific purposes such as for exploitation of riches of the arctic if need arises.

**Challenges for Nuclear Energy**

1. Public opinion against use of nuclear powered merchant ships mobilizing political pressures for restriction of trade and port access.
2. Recycling and dismantling decommissioned nuclear powered submarines/vessels has become a major challenge for US & Russian navies.
3. Initial cost of constructing a nuclear powered vessel is exorbitant.
4. Exaggerated fears about safety that operating a vessel fitted with nuclear reactor in stormy ocean conditions may subject it to undue stresses leading to disastrous situations is perhaps the largest obstacle.
5. LNG is predominantly methane, which is a substantially worse greenhouse gas than CO2. Probability of methane slip i.e. release of unburned natural gas either through the engine exhaust or during bunkering or uses otherwise is a cause of concern and needs to be addressed as the GHG effect of 1 Kg of methane discharged to the atmosphere is the equivalent of 21 Kg of CO2 being emitted.

- **Solar energy:** Solar energy can be utilized for generation of electricity on board ships through photovoltaic cells. Electric power thus produced through use of solar panels while the vessel is underway can be used for supplying part of the propulsion power or for meeting auxiliary loads. Solar-powered systems have so far been tried and tested on a number of pilot projects on board ships. Trial is also on whereby the electricity generated by the vessel’s solar panels during the voyage is stored in banks of lithium-ion batteries. When the vessel is docked, the electricity stored in the batteries can be utilized for auxiliary loads.
is berthed, all of its power needs can be supplied by the battery system, allowing for the diesel generators to be shut down, resulting in zero emissions while the vessel is in port.

- **Wind power:** The potential of wind energy to be used for ship propulsion is substantial and forms an attractive alternative for certain services and operational conditions. The modern versions of the wind technologies are currently under pilot testing and are expected to form part of the future ship power systems. Rotors placed on the deck of a ship can generate thrust by taking advantage of the Magnus effect. Similarly, a kite attached to the bow of a ship can utilize wind energy to substitute power of the ship’s engines. A towing kite system is shown in the figure 1.2.11. The kite provides a thrust force directly from the wind. The system consists of the kite, control lines with a control node, a hawser connection to the forecastle, a winch and the bridge control system. Commercial kites currently range from 160 to more than 300 m² and can substitute a propulsion power up to 2000 Kilowatts depending upon wind conditions and ship’s speed. Generally, the systems are attractive for ship speeds below 15 knots. The automatic control system actively steers and stabilizes the kite, optimizing its performance. The relative ease of kite installation for wind propulsion may lead to ship retrofits within the next ten years. However, kite installation will require erection of additional structures for mast support and few additional duties for the crew. Interference with the cargo handling equipment may also not be ruled out.
(e) Fuel Cell technology:
Fuel cells are electrochemical devices that convert the chemical energy of a fuel and an oxidant into electrical energy and heat through a series of electrochemical reactions without open flame combustion. Since the fuel cells combine the molecules of a fuel and oxidizer without burning, much of the pollution of traditional combustion is dispensed with and quite high efficiency is achievable with silent operations.

A fuel cell system can be fuelled by hydrocarbon fuels such as natural gas, biogas, methanol, ethanol, diesel or hydrogen but the potential benefits offered are greatest when the operation is on high-purity hydrogen and oxygen. Fuel cells have found application mainly in naval sector which has provided momentum to the development of fuel cell technology through its application in submarines and naval crafts because of their low power demands as well as desirable stealth characteristics including silent operations, lack of vibrations and reduced infra-red signatures.

Although fuel cell technology offers significant environmental advantages, its marine applications so far have remained limited to auxiliary power units because of the space constrains, slow response to load variations and capital costs involved. In terms of cost per Kilowattel, fuel cells are ten to twenty times more expensive than diesel engines.

It is expected that establishment of emission control areas (ECAs) will provide a boost to the growth of marine application of fuel cells powered by LNG. Currently, a marine fuel cell prototype delivers power in the range of 0.3 MW. Initially, fuel cells powered by natural gas are expected to provide auxiliary power e.g. hotel loads etc. and thereafter supplementary propulsion power in hybrid electric ships. Feasibility studies for fuel cells powered by natural gas report no emission of NO\textsubscript{x}, SO\textsubscript{x}, or particulate matter (PM) and a significant reduction in CO\textsubscript{2} emissions as compared to diesel engines burning similar fuel. It is predicted that fuel cell solutions will replace current power systems when feasibility and reliability of these technologies for ship-board applications are proven.

(f) Nanotechnology:
It is an emerging technology and is the engineering of functional systems at the molecular scale. The term “nanotechnology” is derived from the Greek word “nanos” meaning dwarf, where one millimetre is equal to 1,000,000 nanometre.

Use of nanotechnology needs to be promoted in shipping technology as this offers immediate advantages for following marine application:

- Fuel cell technology becomes cost effective in the immediate future;
- Efficient and flexible solar panels can be produced at reasonable costs;
- Batteries can be produced that store more energy and are much more efficient;
- Plastics & paints can be produced that will store solar power and convert to energy at much lower cost; and
- Clean, potable and low cost water can be produced on-board ships even from polluted water sources such as brackish waters.

(g) Use of shore electricity when in port:
Vessels use auxiliary engines to produce on board electricity while at the dock to power lighting, ventilation, pumps, refrigeration, air conditioning and other on board amenities as well as systems for cargo operations.

On average, ships spent about 100 days in a year in ports consuming on an average about 5 tons of fuel per ship per day during their port stays. Equipping ships and ports with facilities to utilize shore side power capabilities can be a cost effective air pollution reduction mechanism with zero emission potential particularly for container, cruise and refer vessels that call regularly at fixed ports. In Indian context, considering a number of ports already existing and others coming up and deployment of Indian navy vessels along the vast coastline, there is huge potential for emission reduction through this means.

4.3 NAVIGATION ASPECTS
Safety of maritime navigation is most vital to overall maritime safety. The sea can be a cruel adversary and any reduction in safety measures on board ships may have disastrous consequences leading to accidents such as collision, grounding, stranding etc. resulting in loss of life, property and consequential environmental damage. Exponential growth of maritime traffic around the globe has made safety of navigation all the more important. From the pre-historic era of maritime world when the simple hollow wooden crafts were plying into the uncharted waters to a situation
where technical innovations have over the years yielded newer, more precise ways to chart one’s course across the high seas, celestial navigation using rudiments of astronomy (the positions and apparent motions of the sun and the stars) still constitutes the basis of many of the newer techniques of modern navigation and remains the one, unfailling option for navigators. Modern navigation, in a globally integrated transportation system, requires fulfilling four basic objectives in each voyage from start to finish:

4.3.1 Current navigation technologies
One of the fundamental trends in the maritime industry currently has been an increasing reliance on electro-technical, electronic, electro-acoustic, electro-optical and data-processing techniques. In order to help navigators achieve the objectives of maritime navigation in a safe manner. New stringent maritime regulations, complexity of maritime traffic together with availability of modern technologies have motivated ship owners to install newer and most modern nautical marine instruments and systems onto the navigating bridge of merchant ships for navigational safety. Technologies that have been utilized for safe navigation are discussed below:

1. **Marine radars:** These are x-band or s-band radars to provide bearing and distance of ships and land targets in vicinity from own ship for collision avoidance and safe navigation at sea. Now a days, radars are rarely used alone on board merchant ships. They are integrated into a full system of navigation bridge equipment.

2. **Ground based radio navigation systems:** These systems use terrestrial long wave radio transmitters for positioning of vessels. These positioning systems broadcast a radio pulse from a known “Master” location, followed by repeated pulses from a number of slave stations. The delay between the reception and sending of the signal at the slaves is carefully controlled, allowing the receivers to compare the delay between reception and sending. From this the distance-to-each of the slaves can be determined, providing a fix for the vessel.

LORAN (Long Range Navigation) is one such system still in use, which enables ships to determine their positions and speed from low frequency radio signals transmitted by fixed land based radio beacons, using a receiver unit. The most recent version of LORAN in use is LORAN – C which operates in the low frequency portion of the radio spectrum from 90 to 110 kHz. In recent decade, LORAN use has seen steep decline, with the satellite based navigation system being the primary replacement. However, there have been attempts to enhance and re-popularize LORAN mainly to serve as a backup and land based alternative to other satellite base navigation systems.

4.3.2 Satellite Navigation (SATNAV) System
Satellite Navigation system is a system of satellites that provide autonomous geo-spatial positioning of objects. It allows small electronic receivers to determine their location (longitude, latitude and altitude) to within a few meters using time signals transmitted along a line-of-sight by radio from satellites.

A satellite navigation system with global coverage may be termed as a Global Navigation Satellite System (GNSS). As of now, only the United States of America’s NAVSTAR Global Positioning System (GPS) and the Russian GLONASS are fully globally operational GNSS. Global coverage for each system is generally achieved by a satellite constellation of 20~30 medium-earth-orbit satellites spread between several orbit planes.

The Indian Regional Navigational Satellite System (IRNSS), being developed by Indian Space Research Organization (ISRO) under the total control of the Government of India, is going to be an autonomous regional satellite navigation system. It will consist of a constellation of seven navigational satellites. All the seven satellites will be placed in Geostationary Orbits to have a larger signal footprint and lower number of satellites to
map the region. It is intended to provide an all-
weather absolute position accuracy of 7.6 meters
throughout India and within a region extending
approximately 1500 kilometres around it. A goal
of complete Indian control is envisaged with the
space segment, ground segment and user receivers
all being built in India.

4.3.3 Automatic Identification System
The Automatic Identification System (AIS) is an
automatic tracking system used on board ships
by Vessel Traffic Services (VTS) for identifying and
locating vessels by electronically exchanging data
with other nearby ships and AIS base stations.
AIS information supplements marine radar, which
continues to be the primary method of collision
avoidance. Vessels fitted with AIS can be tracked
by AIS base stations located along coastlines or;
when out of range of terrestrial networks, through
a growing number of satellites that are fitted with
special AIS receivers.

4.3.4 Long Range Identification and Tracking
System (LRIT)
It is a designated International Maritime
Organization (IMO) system designed to collect
and disseminate vessel position information
received from IMO member states ships that
are party to International Safety of Life At Sea
(SOLAS) Convention. LRIT is a satellite based
real time reporting mechanism that allows unique
visibility to position reports of vessels that would
otherwise be invisible and a potential threat to
safety and security. LRIT complements existing
classified and unclassified systems to improve
maritime domain awareness.

4.3.5 Bridge Navigational Watch & Alarm System
(BNWAS)
BNWAS is a monitoring and alarm system which
notifies other navigational officers or master of
the ship if the officer on watch does not respond
or he/she becomes incapable of performing the
watch duties efficiently that may lead to maritime
accidents.

4.3.6 Future navigation technologies
Future of ship’s navigation is Electronic-Navigation
or E-Navigation. E-Navigation is the harmonized
collection, integration, exchange and presentation
of maritime information onboard and ashore
by electronic means to enhance berth to berth
navigation and related services, for safety and
security at sea and protection of the marine
environment.

The main objective of the E-navigation strategy
is the substantial and permanent increase of
maritime safety and security of the whole shipping
industry as well as increasing its operational and
economic efficiency.

Three fundamental elements must be in place as
pre-requisite for E-Navigation in future. These are:

1. Worldwide coverage of navigation areas by
   Electronic Navigation Charts (ENC);
2. A robust and possibly redundant electronic
   positioning system; and
3. An agreed infrastructure of communications
to link not only ship and shore but also from
ship to ship.

4.3.7 Shipboard Weather Routing
Shipboard weather routing is defined as an
optimum track of ship route with an optimum
engine speed and power for an ocean voyage
based on en-route weather forecasts and ship’s
characteristics. Within specified limits of weather
and sea conditions, the term optimum means a
maximum of safety and crew comfort, a minimum
of fuel consumption and time underway, or any
desired combination of these factors. It can be
clearly seen, accuracy of determining the optimum
route depends on 3- aspects:

1. Accuracy of prediction of ship’s hydrodynamic
   behaviour under different weather conditions,
2. The accuracy of the weather forecast,
3. The capability and practicability of the
   optimization algorithm.

4.3.8 3D Dynamic Programming (3DDP) Method
for Weather Routing
3DDP method offers quasi-global optimal routing.
Compared with other traditional weather routing
programmes, this new method allows changes
of shipping course and power delivered by the
engine during the optimisation process. Case
studies with real weather conditions have shown
that significant fuel savings could be achieved
by following the route and operation profile
provided by this method rather than traditional
methods. The newly developed 3DDP method of
weather routing has the potential to contribute
to the international push to save fuel and reduce
greenhouse gas emissions.

4.4 SECURITY ASPECTS
Due to international nature of commercial
shipping, security of ships becomes a global
issue involving numerous stakeholders having
varying interests. It broadly deals with securing the legitimate movement of ships on the world’s oceans. Adequate maritime governance and law enforcement capacity at sea is therefore essential in order to ensure security of ships against threats such as that of piracy, terrorist attacks etc. In order to ensure that security of ships is achieved in a manner that facilitates global commerce and preserves the freedom of the seas, co-operation and co-ordination on a multilateral and bilateral basis between national governments, international organizations as well as non-governmental organizations is a must.

4.4.1 Impact of pirate attacks on shipping and trade
Piracy is a criminal act which not only affects the victims but also has severe financial and other repercussions. Somali piracy has developed into an international organized business operation and crime syndicate, which has badly affected the International as well as Indian shipping and the seafarers’ welfare.

Impact on Indian shipping and trade
India is the twelfth largest importer in the world. Approximately 20,000 vessels call at Indian ports in a year carrying about 90% of its total trade by volume, and 70% by value. This accounts for about 51% of its GDP. For the year 2014-2015, India’s total imports were worth US$ 448 billion as against export of US$ 310.3 billion (Department of Commerce). An estimated US$ 110 billion worth of Indian trade transits through the Gulf of Aden and about 75% of its fuel supply is imported from the Middle East. With the spread of piracy attacks further east into the Indian Ocean, a number of Indian industries and other stakeholders have been increasingly impacted by the crime in multiple ways. Indian imports and exports have incurred additional costs by way of increased war risk premium and longer transit times.

According to data from the International Maritime Bureau (IMB), pirates took over 21 vessels in 2014, up from 12 the previous year, with 442 seafarers taken as hostage. Four seafarers were killed in the incidents, 13 were injured and nine were kidnapped from their ships. The bureau’s annual piracy report said that while downward trend in total number of attacks continued, the risk of being attacked while at sea remains a danger. The World Bank reported in 2014 that since 2005, pirates have netted between 315 ~ 385 million USD in ransom paid from 149 ships seized so far.

4.4.2 Current Counter – Piracy Measures
A number of measures have been taken by all concerned to reduce incidents of Somali piracy and mitigate its impact.

- An international combined naval task force with its base in Bahrain has been set up and Maritime Security Patrol Area (MSPA) has been established in the Gulf of Aden for patrolling high risk areas on a routine basis by the coalition forces.
- Internationally Recommended Transit Corridor (IRTC), consisting of 5 nautical mile (nm) wide eastbound and westbound transit lanes separated by a 2 nm buffer zone, has been created for warship patrols to be effective.
- Ship-owners and masters have been advised to register their vessels with the Maritime Security Centre – Horn of Africa (MSCHOA) prior to passing the Gulf of Aden.
- A document, “Best Management Practices (BMP)” has been developed by various shipping industry organizations in consultation with combined naval forces. The document prescribes planning and operational practices for ship operators and masters of ships transiting the high risk areas and gives guidance for implementation of the same. The document is updated from time to time to reflect the changing piracy situation in the regions.
- Concept of using citadel on board ships has been introduced. A citadel is a designated pre-planned area purpose built onboard the ship where, in the event of imminent boarding by pirates, all crew may seek protection. A citadel is designed and constructed to resist entry of determined pirates. It is equipped with basic amenities for the crew and reliable two way communication system capable of lasting for a specified period of time.
- Deployment of privately contracted armed security personnel on board ships has been permitted as per the guidelines issued by the maritime safety committee of International Maritime Organization.
- A number of counter-piracy organizations and trust funds have been created that comprehensively deal with deterrence, suppression of piracy, prosecution of pirates and for providing humanitarian assistance to seafarers and their families who have been affected by piracy.
4.4.3 Future ship security challenges and roadmap for eradicating piracy

With the advancement of technology, there is every possibility that pirates may gain access to highly sophisticated weapons that may include fast attack crafts, high end electronic warfare devices, thermal imaging cameras, improved explosive devices etc. which will make pirate or terrorist attacks lethal.

Development of new techniques and capabilities, constant vigilance and realistic training will be necessary in order to locate, outmanoeuvre, deter or defeat such attempts in future by the pirates. Further, focusing on strengthening state authority, good governance, law enforcement and economic development of fragile coastal states and stabilizing and supporting failed states should be the long term goals for combating and eradication of piracy and armed robbery at sea.

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5.0 IMPLEMENTATION STRATEGY

5.1 STRATEGIES FOR TECHNOLOGY DEVELOPMENT

Shipping is an International business and if India has to develop its shipping infrastructure for international trade, the country has to comply with international rules and regulations as specified by the International Maritime Organization (IMO). Rising fuel prices, due to dwindling fossil fuel reserves, together with stringent emission regulations owing to environmental concerns, are the two leading factors influencing change in the shipping industry.

In times to come, the ship owner would continue to be the most important stakeholder in the development of new technologies to address the present and future energy and environmental challenges. Sustained investments in research and development by the government will be equally important. Strategies for technology development, therefore, have to be based on short, medium and long term goals.

5.1.1 Short to medium-term goal (till 2020)

A short to medium-term approach must be aimed towards existing ships, and may include:

(a) Adoption of best practices for fuel efficient ship operation through Ship Energy Efficiency Management Plan (SEEMP). Operational measures such as improved voyage planning, weather routing, speed and trim optimisation, more frequent hull and propeller cleaning etc., will minimise wastage of energy, reduce fuel consumption/ GHG emission and thereby improve energy efficiency of ship operation. Use of information and communication technologies can play a very important role in providing technology solutions towards optimisation of these operational measures.

(b) Technical measures may include fitment of appendages for improvement of ship’s propulsion efficiency waste heat recovery systems, energy efficient electric appliances, a new propeller, and application of low friction hull coating, among others. Measures such as use of low sulphur fuel, sea water scrubbing, Selective Catalytic Reduction (SCR) and engine tuning may be required to meet legislative requirements in emission control areas.

(c) While the ships are in the port, use of shore electricity can be a cost effective and environment-friendly solution.

(d) Maritime communication network in India should also be strengthened through the use of the following systems:
   • Long Range Identification and Tracking (LRIT) system;
   • Automatic Identification System (AIS); and
   • Indian Regional Navigational Satellite System (IRNSS).

(e) Mobile towers with powerful signals around fishing hamlets need to be constructed and mobile companies persuaded to enhance their coverage at sea, even using the existing light houses around the Indian coastline. This will not only enhance safety and security of maritime navigation in and around the Indian subcontinent, but also protect our fishermen through incorporation of alerts in their mobile sets, in case their fishing boats cross the danger zone.

5.1.2 Medium to long term goal (2020 onwards)

With the ever increasing requirements for safety, security, environmental and efficiency performance, environmental and efficiency demands will be the main drivers for technology development for the maritime industry beyond 2020.

(a) New ships will need to be highly energy efficient through implementation of Energy Efficiency Design Index (EEDI) concept at the design stage of ships itself.

(b) Some of the key technologies in achieving these goals include hydrodynamic optimisation by design innovations for low ship resistance and improved propulsive efficiency, and use of computational fluid dynamics.

(c) Research must be undertaken for developing promising technologies for energy generation, including alternative fuels like biofuels, LNG,
methanol, hydrogen, etc.; fuel cell technology or non-fossil renewable natural sources of energy like wind, solar power, etc.

There are numerous other environmental issues on the agenda of IMO that are set to become important after 2020. Those expected to be most significant from a regulatory perspective are black carbon emission, hull bio-fouling and underwater noise.

While basic research is possible, it may be time consuming and may not yield the desired results. It will be better to import latest technology through already established players in the international market under license and then build on the imported technology through indigenous research, customised to Indian needs. This has been successfully done in other countries such as Japan, South Korea and China.

As a step towards “MAKE IN INDIA” initiative of our Hon’ble Prime Minister Shri Narendra Modi, ship building and development of engine technology may be taken up first.

Use of Information technology (IT), which is already in an advanced stage of development in India and related Indian talent, can play an important role for the development of advanced indigenous technology and must be encouraged. Blue sky research must also be undertaken as a long term goal.

**TABLE 5.1: ROADMAP PLAN SHIPPING TONNAGE**

<table>
<thead>
<tr>
<th>SHORT TERM (0-5 YEARS)</th>
<th>MEDIUM TERM (5-15 YEARS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Favourable cargo support policies and strict adherence to cabotage regulations in order to promote Indian ship owners. Provide financial incentives in order to create level playing field for Indian ship owners.</td>
<td>Develop strong Indian merchant marine fleet having balance representation of all segments i.e. oil, bulk, container, cruise, LNG / LPG etc.</td>
</tr>
</tbody>
</table>

**COASTAL SHIPPING/INLAND WATER TRANSPORT**

<table>
<thead>
<tr>
<th>SHORT TERM (0-5 YEARS)</th>
<th>MEDIUM TERM (5-15 YEARS)</th>
<th>LONG TERM (15-25 YEARS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provide adequate depth of 7-9.5 meters in non-major ports around the Indian coast and about 3.5 meters in the inland waterways through large scale dredging Provide concessional finance for acquisition of coastal and inland vessels</td>
<td>Develop port infrastructure in the inland regions and along the river channels Broaden approach roads leading to ports for improved movement of containers/cargo to and from inland regions Develop an integrated transport policy or an institutional mechanism that encourages and promotes multi-modal coordination with reasonable share of road, rail, coastal and inland shipping</td>
<td>Development of sustainable Indian Maritime transportation system (International).</td>
</tr>
</tbody>
</table>

Rationalise entire tax structure in line with other maritime nations, which offer tax free regime to shipping.

Favourable cargo support policies and strict adherence to cabotage regulations in order to promote Indian ship owners.

Provide concessional finance for acquisition of coastal and inland vessels.

Develop a strong Indian coastal/Inland vessels fleet.
As a step towards "MAKE IN INDIA" initiative, provide incentives to shipbuilding industry by way of subsidy or tax benefits and grant "Infrastructure" status for its promotion.

- Decongest major ports by promoting non-major ports.
- Streamline cumbersome procedures for grant of environmental and other clearances towards creation of port infrastructure.
- Build mobile towers with powerful signals around fishing hamlets along the Indian coast for communication and safety of Indian fishermen.

Create Trans-shipment hub ports at least one on the east coast and one on the west coast with adequate draft and good connectivity to hinterland, capable of accommodating largest container ships.

- Strengthen Maritime communication network in India through Long Range Identification and Tracking (LRIT), Automatic Identification System (AIS), Indian Regional Navigational Satellite System (IRNSS) and other such systems.
- Improve Port reception facilities for reception and processing of pollutants from ships in line with best International practices.

Port led development: Create Port facilities with more number of berths and adequate facilities to berth large ships together with adequate repair facilities (Integrated ports with loading, discharging, bunkering and repair facilities including dry-dock).

- Enhance and strengthen safety and security of Maritime navigation in and around Indian Subcontinent for protection of Indian shipping, seafarers and fishermen.
- Develop a satellite navigation system with global coverage on the lines of the United States of America’s NAVSTAR Global Positioning System (GPS) and the Russian GLONASS.
Import and adopt available new technology for Indian shipping (coastal as well as International) and ships built in Indian shipyards. This may include the technology for shipbuilding and related activities through adoption of Energy Efficiency Design Index (EEDI) concept.

Encourage research and development (R&D) for adoption of renewable and alternative energy resources for Indian shipping (coastal as well as International)

Promote LNG as an alternative fuel by providing suitable infrastructure along the Indian coast for coastal/Inland vessels

Encourage efficient methods and technology for ship recycling for earning foreign exchange and employment generation

Institutionalize research and development (R&D) activities together with making available sufficient funds for same

Encourage use of Information Technology and related Indian talent for development of advanced indigenous technology

Encourage blue sky research for energy efficient, environment-friendly and sustainable shipping i.e. green shipping

Development of amphibian vehicle

Encourage shipping companies to provide more training berths without remission to existing manpower. If required, suitable incentives may be provided to ship owners. This will ensure smooth completion of mandatory on-board training requirements and will help attract best talent to opt for maritime profession

Introduce suitable welfare schemes for long term benefits to seafarers

Encourage better marketing strategies for Indian seafarers by enhancing entry standards and improving and standardizing training methods across India

Sensitize the whole nation to view the seafaring profession as one of the attractive and respectful professions in order to attract best talent from hinterland

Provide better income tax reliefs/exemptions to seafarers working on Indian ships in order to attract them to work on Indian ships. This will also make Indian shipping companies more competent and efficient

Encourage Trading-cum-Training ships plying on Indian coast meeting all International standards with necessary incentives provided to ship owners. This will ensure production of qualified and well trained seafarers to the shipping industry

Provide adequate facilities to seafarers to pursue higher studies in the maritime field and openings to undertake shore jobs in the maritime industry in between sailings in order to make the seafaring as an attractive and knowledge based profession

With this knowledge acquired both on ships and ashore, India has the potential to transform itself into a country capable of exporting knowledge to the world shipping rather than that of a skilled manpower supplying nation
6.0 BLUE SKY RESEARCH

6.1 HYDROGEN AS AN ALTERNATIVE FUEL
Although hydrogen has the potential to become the ultimate clean fuel in the long term, to be considered as a practical alternative to conventional marine fuel oils, it has to overcome a number of challenges.

For hydrogen to replace conventional marine fuel oils as a truly zero emission fuel, it will need to be produced using established or sustainable production processes that are currently the focus of worldwide research and development (R&D) including electrolysis, photo-electrolysis, high temperature decomposition, photo-biological production and thermo-chemical splitting.

In addition to ‘green’ production technology, hydrogen storage technology will also be required to be improved. Research and development worldwide currently is focused on the development of hydrogen storage technologies such as organic hydrides and carbon nanostructures which, if realised, will almost revolutionise the shipping industry as well as all other transport sectors.

6.2 CARBON CAPTURE AND STORAGE (CSS) ON BOARD SHIPS
In general, carbon capture and storage is the process of capturing CO$_2$ large point sources such as fossil fuel power plants, and storing it in such a way that it does not enter the atmosphere. Storing CO$_2$ in geological formations is currently considered the most promising approach for GHG reductions. It can also be applied to smaller sources of emissions such as commercial ships. In order for CCS to be suitable technology for the maritime industry, research initiatives for novel designs have to be undertaken for on board capture and temporary storage of CO$_2$ emissions for ships in transit. The ships can then store the CO$_2$ until discharge into CO$_2$ transmission and storage infrastructures at the next suitable ports, or to a specialised discharge facility.
6.3 BIOMIMETIC DESIGNS FOR DEVELOPMENT OF MORE EFFICIENT MARINE SYSTEMS
Most of the recent developments in the technology have been inspired by nature. The area of biomimetics involves the study of systems, processes and methods found in nature and using them as basis for solving engineering problems. For example, the propulsion technique used by marine animals has been optimised by millions of years of biological evolution and could, therefore, be considered as an optimal solution for underwater propulsion. Similarly, many large and slow moving animals like sharks, whales and dolphins are able to effectively prevent bio-fouling on their skin. The same technique may be utilised for development of advanced paint technologies in order to limit bio-fouling of the ship’s hull surfaces.

6.4 FUTURE MARINE APPLICATIONS OF NANOTECHNOLOGY
Future marine applications of nanotechnology may include:
(a) Invention of a material other than steel for construction of ships, which is lightweight and leads to lower fuel consumption and hence increased energy efficiency. Research into nanotubes/composites have revealed:
- Increased mechanical strength due to high modulus of elasticity and excellent tensile strength, which is five times higher than that of steel at only one fourth of the specific weight;
- Enhanced electrical conductivity comparable to that of copper allowing non-conductive plastics to be transformed into conductive materials; and
- Enhanced thermal conductivity matches thermal conductivity of diamonds, the best natural thermal conductor of all materials.
(b) Nano scale sensors and devices may provide cost-effective continuous monitoring of the cargo spaces over time. These may also support an enhanced transportation communication infrastructure that can communicate with vessel-based systems to help navigators maintain lane position, avoid collisions, optimise weather routing, and other such activities.

6.5 THE THREE-DIMENSIONAL NAVIGATION CHARTS FOR FUTURE NAVIGATION
A nautical chart is a graphic representation of a maritime area and adjacent coastal regions. Depending on the scale of the chart, it may show depths of water and heights of land (topographic map) and other data relevant for navigation. Nautical charts are essential tools for maritime navigation.

The Electronic Chart Display and Information System (ECDIS) is a development in the navigational chart system. With the use of the electronic chart system, it has become easier for a ship’s navigating crew to pinpoint locations, and attaining directions are easier than before. The ECDIS utilises Global Positioning System (GPS) to successfully pinpoint the navigational points.

There is a broad interest to utilise video signals in real-time with additional data. The advantages are especially the enhancement of hidden structures and elements. A navigational device, which overlays 3D nautical information onto camera signals of the actual environment may be used in the future.

6.6 SHIPPING ACROSS ARCTIC OCEAN
Because of presence of huge quantities of fossil fuel, natural gas, minerals and precious stones, Arctic regions are important.

Physical parameters that pose challenges to shipping activities in the Arctic region are mainly related to the high latitudes and extremely low air and sea water temperatures. Ships operating in the Arctic environments are exposed to a number of unique risks. These include:
(a) Sea ice and icebergs posing hazards to the integrity of ships’ hulls. These can impose additional loads on the hull, propulsion systems and appendages. Cold temperatures may reduce the effectiveness of numerous components of the ship ranging from deck machinery and emergency equipment to sea suction;
(b) Icing from sea spray, precipitation and fog affecting safety of the ships and posing stability problems;
(c) Polar lows (small storms), those are difficult to predict and detect;
(d) Wind chills, which are combinations of low temperatures and strong winds, affecting safety of the ships and posing health hazards;
(e) Remoteness of the area that makes search and rescue, clean up and emergency operations and communications difficult and costly;
(f) Long spells of darkness in winter;

(g) Reduced visibility from fog and precipitation;

(h) Less reliable weather forecasts, relative lack of good charts, communication systems and other navigational aids posing challenges for the mariners; and

(i) In general, information on the meteorological and oceanographic conditions like winds and waves in parts of the Arctic with seasonal or round-the-year ice cover is poor.

6.6.1 India’s Role in the Arctic Region

The race for a share of the enormous reserves of fossil fuel and control of transit routes in the Arctic region is heating-up. The five coastal states in the frontline of the high-stakes hunt are the Danish commonwealth (including self-governed Greenland and Faroe Islands), Russia, Norway, Canada and the United States of America (USA). Finland, Sweden and Iceland are also stakeholders in the Arctic rim (Figure 1.6.1).

India already has an Arctic presence with its research station in Norway’s northern Svalbard Archipelago (a group of islands). India’s Arctic observatory – Himadri – is a study station in New Aalesund, Spitsbergen. It is the largest research station in Norway’s Svalbard Archipelago, which is located about 1,200 km from the North Pole. India is also an observer in the International Arctic Science Committee (IASC) based in Potsdam, Germany, which in turn holds observer status in the Arctic Council. India has also applied to IASC to join as full member.

Under the circumstances, India must join the Arctic Council and work for furtherance of its interests in the Arctic region. Further, India should deeply engage with Norway as the one state that may not only aid and advance the Indian cause, but also help rope in countries like Sweden and Finland towards protecting its interest and shaping the future of the Arctic region.

**FIGURE 6.1: THE FIVE COASTAL STATES IN THE FRONTLINE OF THE HIGH-STAKES HUNT FOR FOSSIL FUELS[1]**

*The Guidelines for Ships Operating in Ice-covered Waters: Maximum extent of application*
India should also develop its technological capabilities and technical knowhow of operating vessels in the arduous environments of the Arctic. Powerful icebreakers are a key investment for countries having major interests in the Arctic region, as a necessity for all year access through the ice. Therefore, India should develop technological capabilities to build and manage such powerful ice-breakers, preferably nuclear powered ones. The specific needs of the ice-breaking ships make them one of the only cases, where nuclear propulsion is economically practical – barring nuclear submarines, which take advantage of the fact that the nuclear reactors do not require oxygen to run.

6.7 GAS PRODUCTION FROM HYDRATE RESERVOIRS
Gas hydrates are ice-like crystalline materials that contain water and gases. The gas molecules are trapped in the cage like structure of the surrounding water molecules, leading to a tight structure. One volume of hydrate could release 150 to 180 volumes of natural gas at standard conditions. The high concentration of natural gas puts the energy content of hydrate bearing formations at par with bitumen and heavy oil reservoirs, and much higher than the energy content of other unconventional sources of gas, such as coal bed methane.

It is estimated that the amount of natural gas trapped in hydrates around the world is approximately twice that of the recoverable gas in conventional reservoirs. India should also develop its technological capabilities and technical knowhow in this field for exploiting the potential towards improved energy security.

REFERENCES
## 7.0 CONCLUSION AND RECOMMENDATIONS

The shipping sector, besides transport of goods and passengers, presents ample opportunities in the fields of ship building, ship repairing, port infrastructure, human resource development, logistics and supply chain management and other related activities. India as one of the fastest growing economies of the world, needs to bring radical changes in shipping related activities.

1. Growth of Indian tonnage has not kept pace vis-à-vis development of our trade. Lack of cargo support and financial incentives have led to the share of Indian shipping companies in carrying Indian cargoes decline to abysmally low figures. India needs to adopt Cabotage and cargo support policies like rest of the world in order to improve Indian tonnage to respectable levels.

2. The entire tax structure in the country needs to be rationalised and brought in line with other maritime nations, which offer tax free regime to shipping. This must be done in order to create a level playing field for the Indian ship owners.

3. An integrated transport policy or an institutional mechanism that encourages and promotes inter-modal coordination with reasonable share of road, rail, coastal and inland shipping with seamless integration needs to be developed for growth of coastal and inland shipping.

4. A number of non-major ports with good connectivity to hinterland along the east and west coast of India having draft of 7-9.5 metres need to be developed for growth of coastal shipping. Port infrastructure in the inland regions and along the river channels with good connectivity to hinterland and capable of accommodating small vessels and barges needs to be created for growth of inland shipping. This would entail large scale dredging operations of the existing ports and the river channels.

5. Transhipment hub ports with good connectivity to hinterland, at least one on the east coast and one on the west coast for handling of container traffic capable of accommodating present day largest container vessels of up to 19224 TEUs need to be developed so that our dependence on foreign ports for transporting Indian containers may be minimised.

6. Steps need to be taken to enhance safety and security of maritime navigation in and around Indian subcontinent and also protect our fishermen.

7. Strengthening of maritime communication network in India through Long Range Identification and Tracking (LRIT) system, Automatic Identification System (AIS), Indian Regional Navigational Satellite System (IRNSS) must be prioritised.

8. Emission abatement systems, better hull forms, better engines, new propeller technology and operational optimisation have the potential to bring improvement in efficiency of the shipping industry and compliance with contemporary International Rules and Regulations.

9. There are numerous other environmental issues on the agenda of IMO that are set to become important after 2020. Those expected to be most significant from a regulatory perspective are black carbon emission, hull bio-fouling and underwater noise. Pro-active steps need to be taken to address the implication of these regulations.

10. Promising technologies for energy generation such as from alternative fuels (biofuels, LNG, Methanol, Hydrogen etc.), fuel cell technology or non-fossil renewable natural sources of energy (wind, solar power etc.) to be developed to achieve the medium and long term goal of low energy and low emission i.e. green shipping.
11. Use of Information technology (IT), which is already in an advanced stage of development in India and related Indian talent, can play an important role for the development of advanced indigenous technology and must be encouraged. Blue sky research must also be undertaken as a long term goal.

12. Maritime industry has very high global manifestation in all aspects of its operations, and there is an urgent and compelling need to augment pool of high quality seafarers in right quantities at the right time. In order to achieve this, the Maritime Education, Training and Research should now be aimed at improving the quality and skill sets of seafarers through high levels of standardization of Maritime Training Institutes across India.
INTRODUCTION

Air transport plays a key role in the modern, globalised economies, not just in terms of being the fastest and the most reliable means of transport but as a key enabler for the economic growth and development of countries. Air transport is a network industry which connects the different geographical areas of the world to facilitate economic transactions between them, and therefore is a cause as well as effect of economic growth.

The growth in the aviation sector has put pressure on the aviation systems like never before thus creating problem of congestion across the world which further adds to the environmental problems of GHG emissions and noise pollution. The focus of aerospace technologies has been on continuous improvement in fuel efficiency and reduction in noise and CO$_2$ emissions by the aircraft. However, climate change is today a very serious challenge and therefore sustainability is the key word for all future technological advancements. One of the reasons for airspace congestion has been the gap between the airborne and ground based technologies, whereby the existing navigation capabilities of the modern aircraft are not fully utilized resulting in sub-optimal flight profiles and longer routing both adding significantly to the carbon as well as noise footprint of civil aviation. A considerable reduction in overall emissions along with capacity enhancement can be achieved by adopting efficient operational procedures and airspace design utilizing the existing technologies of the modern aircraft for optimal flight profiles.

The use of performance based navigation can lead to an optimum descend flight profile thereby reducing the aircraft noise and fuel burn, aircraft can operate on most optimal routing, airspace capacity can be increased significantly and thereby the aircraft getting optimum cruising level and thereby saving on precious fuel and carbon emissions.

Air transport has shown consistent high levels of growth in India in last two decades and this trend is expected to continue in the next few decades as well with about 10% growth projected in the next two decades. The Government has announced a comprehensive National Civil Aviation Policy (NCAP) 2016 to address the challenges in the sector so as to achieve the growth potential. The NCAP targets to create an ecosystem to enable 300 million domestic ticketing by year 2022 from the current figure of 70 million and to further increase the same to 500 million by 2027[1]. The traffic growth of such magnitude warrants significant ramp-up of airspace and airports capacity.

In last decade, we have created Greenfield airports of Hyderabad and Bengaluru and modernization of Delhi and Mumbai was completed successfully through public-private partnership creating world class international airports in the country, which aided the current growth in the sector. In order to sustain the projected growth of air traffic serious efforts would be required to create new green field airports as well as upgrade the existing airports.
for enhancing the capacities. At present there are about 133 airports in the country which include 24 international airports, 8 customs airports, and 101 domestic airports[2]. Besides these, there are about 400[3] unused landing strips in the country which are owned by state governments/other entities. Revival of these unused strips is a key proposal under NCAP in order to enhance regional connectivity.

India has embarked upon a serious technology drive to upgrade its Air Navigation Services (ANS) infrastructure and technologies in order to enhance the airport and airspace capacity. Airports Authority of India (AAI) which is responsible for provision of ANS in the country has taken up restructuring of airspace in the country along with investment in Air Traffic Management (ATM) automation, radar surveillance systems, reduced separation requirements in performance based airspace design, as well as space based technologies like ADS-B (Automated Dependant Surveillance-Broadcast) for surveillance and GAGAN (GPS aided GEO Augmented Navigation) for navigation. GAGAN, a satellite based technology for augmentation of GPS signal, will be 4th of its kind of system after US(WAAS), Europe(EGNOS), Japan(MSAS) and will have a footprint from Africa to Australia. GAGAN will eliminate the need for ground based radio navigation aids which are costly, difficult to maintain, and have limited range. A suitable airborne GAGAN receiver allows the equipped user to not only determine its position far more accurately than GPS but also provides timely integrity alerts as to when the signal may not be usable particularly during the safety critical landing phase of a flight. GAGAN would have a large number of non-aviation application including in all the other modes of transportation.

Air transport will be even more vital for the modern societies of future, and we shall travel more by air in future leading to further congested skies and airports. Conventional hydrocarbon fuels may eventually become unviable/unavailable, and alternate sources of energy which are clean and sustainable will have to be used. Aircraft will have to be far more energy efficient, safer, quieter, and have lower carbon footprint and eventually emission free. The evolution of technologies in the air transport will therefore be driven by reduction in carbon footprint and aircraft noise, capacity enhancement, and safety of air transport system.

As the aircraft is the central element of air transport and source of all the noise and carbon emissions, the focus of future aircraft technologies would be in meeting the objectives of sustainable air transport through reduced noise and carbon emissions. The basic consideration of all the aircraft technologies remains to be on:

i) reduction in drag and aircraft weight for reduction in fuel burnt
ii) improved propulsive and thermal efficiency of the engines
iii) improved navigation performance so as to fly shortest path
iv) to increase airspace capacity through reduced separation minimums

However, the targets of meeting carbon neutral growth and further reduction in emissions requires drastically new thinking, designs and technologies. A systems approach needs to be applied for an integrated development of technologies along with the required regulatory certification regime for the airborne as well as ground elements for an effective deployment of the evolving technologies and optimum utilization of the capabilities of modern day aircraft in order to achieve the operational efficiency.

In order to achieve global harmonization in deployment of advanced technologies, International Civil Aviation Organization (ICAO) has adopted Aviation System Block Upgrades (ASBU)[4] which proposes a frame work for modular implementation of system upgrades around the existing and emerging aviation technologies, along with the required changes in the regulatory standards and operational procedures as an integrated module for a defined operational improvement. This approach identifies the various dependencies and allows for a coordinated action on part of various stakeholders for an effective application of evolving technology solutions as well as provides an effective roadmap for technology development in a coordinated manner. Sustained viability of airline industry
is very crucial for the air transport sector and therefore, the technologies have to focus on creating value for the airline operators and overall reduction in cost of operations.

Aerospace R&D and manufacturing in India was for long an exclusive domain of public sector units namely HAL, NAL, and DRDO etc. who have acquired capabilities across the value chain of aerospace manufacturing mainly focused on defence requirements and supported the creation of SMEs as vendors in a limited way. Aerospace manufacturing is essentially a global industry and its supply chain is characterized by high end technologies with very long development cycles, huge development costs; long gestation period between the initial investment and revenue generation; economies of scale and scope; and very stringent certification requirements. The supply chain therefore has an inherent risk and entry barriers which is also reflected in the concentrated structure of the aerospace industry with few big global players. However, owing to significant cost pressures in the global aviation industry, there is a structural shift in the global aerospace supply chain and the OEMs have resorted to risk sharing arrangements with suppliers to develop new products, exploring low cost manufacturing options for airframe and systems and thereby opening new opportunities for countries like India to augment its presence in the global aerospace supply chain.

The aerospace and defence sector was opened for private participation including FDI upto 26% in 2001 which was increased upto 49% in 2015 and the same has now been permitted upto 100% in 2016[5] wherever it is likely to result in access to modern technology. The “Make in India” programme launched by the Government also envisages supporting and promoting manufacturing in the country and aerospace and defence is one of the key pillars of this programme. India, being one of the largest markets in the civil as well as defence equipments is an attractive investment destination for global OEMs. Moreover, the Government policy on offsets which requires the vendors to source local input of 30% of the total value in case of defence purchase can provide the much required boost to the high technology manufacturing and technology development in the aerospace.

An effective management of these offsets investment by the aerospace companies can provide a significant boost to the aerospace manufacturing capabilities in India. In view of emerging opportunities in the sector, a lot of reputed industrial houses have entered the fray in joint ventures and technical collaboration with established global and local players and are targeting larger set of capabilities in the sector.

The success of Indian aerospace manufacturing will depend on being competitive in terms of delivering the required standards of quality, adherence to timelines, at the lowest cost, which will require creation of an efficient aerospace ecosystem in the country based on public private partnership. The approach towards aerospace manufacturing must be very practical with decisions on i) “make or buy” for critical technologies to be based on the economics of time and money and ii) a focus on development of capacities in the sector and moving upwards in the value chain. We should, therefore, target the capabilities in aircraft design and system integration with indigenous as well as imported technologies/subsystems in the most economic and time bound manner to address the challenges in the sector. India’s huge procurement requirements in both civil and defence sectors along with sustained long term demand scenarios have created an opportunity to quickly move to the next level by capitalizing on the advantage of available talent pool of technical resources. This would require a serious thrust on R&D with a framework to support innovation around the existing strength and ability to deliver global standards of quality at a much lower cost.
Over the last decade we have seen air transport in India transform from an elitist mode of transport to basic infrastructure and the mainstay of economy. Even though the growth of air transport remains susceptible to economic turmoil and slowdown in the short run, it has largely been resilient globally in longer term.

2.1 TRAFFIC GROWTH
India has witnessed a phenomenal growth in the last two decades and more so in the last decade, some of the highlights of this performance are:

i. The domestic passenger traffic registered a growth at a CAGR of 10.10% over the last decade (2006-07 to 2015-16) while the international passenger traffic grew at a CAGR of 8.75% during the same period[2] as shown in fig 2.1

ii. The domestic cargo registered a volume growth at a CAGR of 7.6% over the last decade (2006-07 to 2015-16) while International cargo traffic grew at a CAGR of 4.7% during the same period[2].

iii. The number of non-scheduled operators providing on demand charters, business jets, and helicopter services have also shown a significant growth. The total numbers of operators with NSOP (Non-Schedule Operators Permit) increased from 66 in 2006-07 to 123 in 2015-16, and the total number of aircraft in this category increased from 229 to 406 in this period[2].

The growth witnessed in Indian air transport in the last decade is expected to continue in the next few decades and India is expected to become the third largest aviation market by 2020[7]. Air transportation will grow beyond the present system of scheduled operations to include a variety of on-demand / non-scheduled operations such as emergency/medical evacuations, disaster management, internal security, search and rescue, fire-fighting etc.
2.2 DRIVERS FOR GROWTH
Economic growth is a key driver for demand of air transport, and India is expected to witness a sustained long term economic growth for next few decades. Some of the key factors driving sustained traffic growth of air transport in India:

- Growing urbanization
- Sizeable and growing middle income group with high aspirations
- Growing tourism
- Untapped market potential; under-penetrated market for air transport.
- Growing demand for air cargo: Global outsourcing, express industry, free trade agreements, and global integration of businesses driving demand for business related travel and cargo
- Demand for air cargo: Global outsourcing, express industry, free trade agreements, and global integration of businesses driving demand for business related travel and cargo
- Government’s thrust on regional/remote area connectivity
- Demographic dividend: Large and growing proportion of working age group
- Increasing accessibility and affordability of air transport; through low cost carriers, ensuing competition, expanding infrastructure and easy availability of credit.

The traffic growth forecast of passenger carried and cargo operators are shown in figure 2.2 and figure 2.3.

2.4 CHALLENGES FOR AIR TRANSPORT INDUSTRY
2.4.1 Environmental challenge of CO₂ and Noise emissions:
Globally, the air transport system is facing the challenges of congestion leading to environmental degradation which are only going to be worse in the future in view of growing demand. The focus of technology development has been on continuous improvement in the existing technologies with a focus on increasing efficiency, and reduction in noise and CO₂ emissions. This has resulted in reduction in fuel burn by 70% and aircraft noise by 75% over the last 40 years[9]. The contribution of air transport to global anthropogenic emissions is estimated by Intergovernmental Panel on Climate Change (IPCC) as 2% which is growing at the rate of 2-3% every year and projected to grow to 3% by year 2050[10]. The impact of aircraft noise on the communities nearby an airport is another serious environmental challenge which results in added costs in the form of mandatory noise abatement procedures, which put restrictions on the preferred runway or even an absolute night curfew at certain airports.

Climate change is a major global challenge threatening sustainability of all the industrial activity including air transport industry. There has been a continuous improvement in efficiency and reduction in noise and CO₂ emissions of the aircraft in past. However, to meet the targets of carbon neutral growth in future, drastic changes are required in aircraft technologies and ATM and operational procedures.

2.4.2 Security post 9/11 is becoming as a major challenge for the aviation community amidst growing terrorist attacks the world over. The security setup at the airports also adds to the capacity constraints at the major airports besides the inconvenience to the travellers. Therefore, there is a need for non-intrusive technologies and use of advanced information technology for effective security system with minimal passenger inconvenience.
The traffic growth forecast up to year 2031-32 from a Ministry of Civil Aviation [8]
2.4.3 Viability of Airline Industry: It is very crucial for sustaining growth and investments across the value chain of air transport. The airline industry in the last decade saw a phenomenal traffic growth albeit without much of profits. The airline industry is under huge debt to fund this growth, and there is a further capital requirement for aircraft acquisition in future. Such high level of debt and high interest cost make things really difficult for the industry during the downward economic cycle. The competitive landscape for airline industry has transformed radically in last decade with entry of low cost carriers, and now the foreign airlines being permitted to invest upto 49% in Indian carriers.

The operating environment for the airlines besides the fierce competition and excess capacity is characterized by the following challenges:

- **Demand side challenges:**
  - Cyclicality as it is highly correlated with state of national and global economy.
  - Short-term seasonal variations.
  - Perishable nature of the service/product.

- **Supply side on the contrary is fairly rigid and regulated which makes it impossible to adjust supply to match the fluctuating demand particularly in the short run.**

- The cost structure for the industry is quite rigid. Aviation Turbine Fuel (ATF) is the single most cost factor which is about 40-50% of the total operating cost. The sector has got big relief in form of lower crude prices recently.

- With cascading central and state taxes, the prices of ATF are very high as compared to global averages. Also the volatility in the ATF prices makes the management of input costs even more difficult.

- The airline industry is also affected severely by the exchange rate risks, as almost all the cost elements including fuel, insurance and freight, maintenance, repair and operation expenses (MRO) and aircraft lease rentals are in dollar terms, where as the earnings are in rupees. Therefore, any sharp unfavourable currency movement makes the operating environment extremely challenging.

2.4.4 Congestion: Air Transport System capacity constraints: The ever-growing demand for air transport has already lead to congestion in the air transport system at the major airports. Airspace and airport congestion not only lead to economic losses but raises many issues related to environment and safety. The congested system is throwing up challenges for meeting the aspirations reflected in the traffic growth forecast. These capacity constraints in air transport system leads to economic losses due to opportunity cost; increased transportation costs; increased transportation delays; unproductive fuel burnt; and environmental losses due to avoidable emissions. The primary reason for the congestion is the increasing gap between demand and supply of key aviation infrastructure: Airspace and Airports. The airspace capacity and airports capacity complement each other and therefore need to be handled in an integrated and coordinated manner by the airport operator and the air navigation service provider.

2.4.5 Shortage of skilled workforce: across all the areas of aviation is another challenge for the industry. Airlines are forced to hire foreign pilots due to lack of sufficiently experienced pilots required for airline operations.
3.0 STATUS OF TECHNOLOGY

The aviation sector is internationally one of the most regulated sectors and the aviation technologies and products are required to comply with very stringent certification requirements laid down by the International Civil Aviation Organization (ICAO). Therefore, the technology development and deployment cycle is a very long process often taking decades before a new technology is implemented. Owing to the nature of aerospace manufacturing industry, there are only a few global players at the forefront of aviation technologies who are in a position to invest huge sums of money for development of new technologies and manage the complex product development cycle as well as provide continuous support over the lifetime of the aircraft. These global players, therefore, drive all the innovation and technology development in the sector. Almost all the technologies in the civil air transport from aircraft to ANS infrastructure are imported in the country and globally latest technologies are therefore available in the country.

In terms of domestic capabilities, except HAL which has developed expertise at tier-1 level in licensed manufacturing of aircraft mainly for defence requirements, the rest of the industry is at tier-3 level in the supply chain. With opening up of the defence manufacturing for private companies and FDI (upto 26%) in 2001, major industrial houses have entered the field and targeting a larger set of capabilities in the sector. Now with the Government’s ‘Make in India’ initiative and opening up the sector for FDI, lot of big industrial houses have entered the fray. In the last two decades Indian technology companies have made significant progress in providing software engineering services to the global aerospace majors. Indian companies are recognized for their capabilities to meet the very stringent quality requirements of the sector. However, the civil aerospace manufacturing ecosystem is still at a nascent stage in the country. This section presents status of aviation technologies in the global context and offers a perspective on the status of aerospace technology and manufacturing capabilities in India.

3.1 AIRCRAFT TECHNOLOGIES – GLOBAL CONTEXT

The basic consideration of all the aircraft technologies remains to be on reduction in drag and aircraft weight for reduction in fuel burn; improved propulsive and thermal efficiency of the engines; improved navigation performance to fly shortest path and also increasing airspace capacity by reduced separation.

3.1.1 Airframe Design, Materials and Manufacturing: Airframe design has evolved over the period of time along with advances in propulsion systems, materials and computational fluid dynamics. Evolution of airframe technology is shown in fig 3.1.

The modern airframes are designed on computers using advanced 3D simulation models based on computational fluid dynamics and analytics, whereby each airframe component can be tested for aerodynamics performance and structural safety under all the possible hostile operating conditions under which an aircraft will operate. The use of CAD results in faster designs and improved accuracy in part design and assembly, improving the quality of designs, and therefore a reduction in time to market. Another important technology used in aircraft design ‘fatigue life analysis’ using computer simulation models to determine the safe life of the components and an effective I&M schedule for all the critical components. Some of the current technologies employed in the area of airframe, design, material, manufacturing and aircraft systems are discussed below:

a) Computational fluid dynamics (CFD) uses numerical methods and algorithms to simulate fluid flows and interactions with surfaces. The advancements in computation power and supercomputers have allowed faster setup and runtimes, better design accuracy, and capacity to handle greater design complexities leading to more efficient aircraft designs and significant saving from reduced wind tunnel and flight validations. Boeing 787 was designed using 800,000 hours of computing time on Cray
supercomputers and 15,000 hours of wind tunnel testing[12].

b) **Wing tip devices** are the angled extensions on the aircraft wingtip which increase the lift generated at the wingtip (by smoothing the airflow across the upper wing near the tip) and reduce the lift-induced drag caused by wingtip vortices, improving lift-to-drag ratio. Gross fuel mileage improvement with winglets was recorded in the range of 4 to 5 percent[12].

c) **Materials and Manufacturing Techniques** have a direct impact on the structural weight, strength, and fatigue performance of the airframe. Advance lighter composite materials are being used in place of conventional aluminium based materials. Boeing 787 uses an airframe comprising nearly half carbon fibre reinforced plastic and other composites[12]. This approach offers weight savings on average of 20% compared to more conventional aluminium designs. Also, advanced manufacturing techniques like ‘laser-beam welding’ and ‘friction stir welding’ are now utilized which help in reducing structural weight as compared to the conventional arc welding and riveting techniques. This happens due to reduction in material required to achieve the required strength of the joint as well as by reducing the number of fasteners employed. These advanced welding techniques also result in smoother finishing of the airframe and thereby improved flows over the boundary layer.

d) **Flight controls**: Fly-by-wire (FBW) technology has come of an age with advanced digital systems that combine flight management, navigation, guidance, control, sub-system health monitoring, and
maintenance indications and therefore maintain the most optimum in-flight profile besides weight reduction. Use of advanced automated flight control technologies provide a greater leeway to the aircraft designers without any compromise on safety in view of better performance range of such systems when compared to human controlled mechanical flight control systems. Use of compact electromechanical actuators for managing secondary control surfaces has further lead to reduction in weight.

e) Passenger Cabin Interiors: Use of lighter material sidewalls, panels, seats, etc. can offer significant weight reduction and thereby a potential to reduce fuel consumption. Use of light weight composites, improved design, and use of plastic fasteners are some of the technologies in this area which have led to reduction in aircraft weight.

f) Electrical Power Systems: Modern aircraft like B787 have virtually eliminated the pneumatic systems which are powered by the bleed air from engine; the only onboard system in B787 based on engine bleed is the engine inlet anti-ice systems. This leads to better efficiency and reduced mechanical complexity of the onboard systems, thereby reduce the maintenance cost with better reliability.

3.1.2 Propulsion Systems
The propulsion system is the most important part of an aircraft which provides the required thrust for an aircraft to fly at desired speeds. The aircraft propulsion system or the engines is also critical as it happens to be the main source of both noise and CO$_2$ emissions which have become the most critical element for sustainability of air transport in future.

Aircraft engines technology has made significant improvement in terms of fuel efficiency and noise emission which is reflected in the fact that despite a 53% increase in traffic along with 41% increase in capacity, jet fuel demand has increased by just 3% since 2000[9]. Fig 3.2 shows the engine fuel consumption trend. Aircraft propulsion system using propellers and fans have better aerodynamic efficiency. However, they are not suitable for high speed subsonic/supersonic aircraft, as propellers suffer aerodynamic losses due to shock waves at such speeds. For low speed air transport and cargo movement, turboprop engines are used as the propulsion system due to their superior fuel efficiency, whereas for high speed transportation turbofans are used.

The performance and fuel efficiency of a turbofan engine depends upon the by-pass ratio (BPR), higher the bypass ratio, higher is the efficiency. The current generation of engines

![Figure 3.2 Engine Fuel Consumption Trends](image)
operate at a BPR of 8 to 10 and the emerging technologies are expected to take efficiency higher with BPR of 10 to 20. Technologies involving use of advanced materials and composites in the system components and enhancement in combustor design have also contributed to lower emissions besides reducing the weight. Some of the technologies related to engine components include lighter composite fan blades and fan case with titanium leading edges, efficient cooling techniques, advance combustor, Nacelles and Chevrons.

3.1.3 Fuels
Aviation Turbine Fuel (ATF) which is petroleum based product continues to be the fuel for the industry. The current energy economy which is carbon intensive is posing a serious challenge in the form of global warming and there is a global consensus that we need to reduce the carbon intensity of our economy. Aviation sector is no exception to this. The rising fuel cost and volatility in prices have been a significant challenge for the aviation industry and efforts are being made to switch to some reliable alternatives for jet fuel. The alternative fuels in this regard need to meet the specifications in terms of extreme handling of temperatures and high energy content and also be mixable (drop-in) with conventional fuel so that it can be used without any major changes in the aircraft engines or the supply infrastructure. Trials are underway to commercialize some of the alternative fuels such as bio fuels.

3.1.4 Avionics
Avionics in the modern aircraft has come of age with fly-by-wire technology based on modern digital computer systems coupled with multifunction display technologies, which automatically acquire, process and present all the pertinent data and information on the pilot’s display. The heart of modern avionics is the FMS (Flight Management System) which is a programmable computer that acquires and processes all the sensor inputs from various subsystems, accepts standardized user inputs, and manages the controls in the most optimized manner for the desired performance. The modern avionics has made it possible for the aircraft to fly with very high degree of navigational accuracy, automatic flight control (auto-pilot), on-board performance monitoring and alerting for sub-systems, collision avoidance, and therefore, enhancing the safety of flight operations.

3.1.5 Air Navigation Services (ANS) Technologies
Air Navigation Service providers operate on the backend of the air transport value chain and provide the necessary Air Traffic Management service and the ground based technology infrastructure in the form of Communication, Navigation, and Surveillance (CNS) equipments and installations.

**COMMUNICATION (COM)**
VHF (Very High Frequency), High Frequency voice communication, Controller Pilot Data Link Communication (CPDLC)

**NAVIGATION (NAV)**
Ground based NDB, VOR, DME, ILS Satellite based GNSS [GPS, GLONASS, and GALELIO]

**SURVEILLANCE (SUR)**
Primary Radar, Secondary Radar, ADS-B, Surface Movement Radar (SMR) & Advanced Surface Movement Guidance and Control System
ATM (Air Traffic Management)

Automation is another layer of technology which processes data in a real time from the different sources like radar sensors, flight data received from other units and controller inputs; presents an integrated air traffic information and control data on an interactive display along with variety of other relevant information for an effective management of air traffic in the given airspace. An effective ATM automation system enhances the traffic handling capacity of an air traffic control unit along with enhanced safety.

Globally, the Air Traffic Management system is quite fragmented leading to inefficiencies in the system, inefficient and insufficient flow of information between the various stakeholders and adds further costs in the form of increased emissions and airspace congestion. The lack of an end to end and real time flow of information between the stakeholders creates challenges for an efficient management of airport capacity adding to the congestion. The coordination needs to be augmented by creating an end to end information network between various stakeholders and creating applications for real time use of such information for an efficient utilization of airspace and ground infrastructure. The present ATM system is not very flexible and slow to meet any changes in the user requirements, and does not make best use of the advanced navigation capabilities and performance of the modern aircraft.

This has been realized by the aviation community the world-over and is reflected in the vision for the NextGen system by US and SESAR(Single European Sky ) by Europe, which target to create a seamless and scalable airspace system through deployment of integrated technology solutions so as to meet the ever-growing demand scenarios from the different users of the airspace. ICAO has adopted ASBU (Aviation System Block Upgrades) which proposes frame work for global harmonization of ATM concepts and modular implementation of system upgrades for a defined operational improvement. The ASBU framework establishes ANS system modules around the currently available aircraft equipage; establishes a transition plan for a global interoperability; and proposes the development and deployment of such modules or system upgrades over four blocks of 5 years, with block 0 starting in 2013. ICAO Global Air Navigation Plan under ASBU framework targets creating globally harmonized ANS system improvements based on the aircraft capability available today, and provides a roadmap for the future modules/blocks for the development of enabling technologies towards a seamless global ANS system. This framework will also guide the ICAO member states, aircraft manufacturer and technology vendors to avoid unproductive expenditures on disparate local systems.

3.2. INDIAN AEROSPACE INDUSTRY

The history of aerospace manufacturing in India dates back to 1940 when Hindustan Aircraft Ltd. was established, which was later on merged with Aeronautics India ltd. and Aircraft Manufacturing Depot, Kanpur to form Hindustan Aeronautics Ltd (HAL), the largest aerospace company. National Aerospace Laboratories (NAL) was established in 1959 under the Council of Scientific and Industrial Research with a mandate of developing aerospace technologies, design and build civil aircraft. There are host of other institutions like Defence Research and Development Organization (DRDO), Bharat Electronics Ltd (BEL). However, India has so far been lagging in aircraft design and manufacturing, even though Inspite of being a part of elite group of nations with space capabilities.

Indian public sector units (namely HAL, NAL, and DRDO etc) have developed significant capabilities across the value chain of aerospace manufacturing for defence sector. However, there are gaps in some of the high end technologies. Indigenous programmes like light combat aircraft (LCA) have suffered chronic delays. Some of the major gaps in the critical technologies include propulsion systems, avionics and flight control systems. The sector was opened for private participation in 2001, and with the growth and emerging opportunities lot of private companies have entered the fray in joint ventures and technical collaboration with established global and local players and are scaling up their capabilities. Almost all the major global aerospace companies have set up engineering and design centres in India, to take advantage of the local talent, and also for the long term business interest.
3.2.1 Public Sector Entities
HAL is the largest aerospace manufacturer of India catering mainly for defence requirements and has acquired significant capabilities and is the mainstay of aerospace activity in the country. HAL has designed and developed Druv/Advanced Light Helicopter with both civil and military versions, and is developing multirole fighter aircraft Light Combat Aircraft/Tejas. HAL has 20 production/overhaul divisions and 10 R&D centres. HAL has been exporting aerostructures and components to leading global OEMs like Boeing and Airbus. HAL has also played a significant role in India’s space programs by participating in the manufacture of structures for Satellite Launch Vehicles[14].

Bharat Electronics Limited (BEL) is a leading defence PSU with capabilities in Electronics and Sensor technologies.

Defence Research Development Organization (DRDO) has developed technologies across the gamut including Unmanned Aerial Vehicles (UAV), Advanced Materials including Composites, Sensors, Flight controls, Avionics etc for various Defence and Missile programmes.

Indian Space Research organization (ISRO) has proven aeronautical capabilities in the space technologies including advanced materials and composites, control systems, satellite navigation systems, propulsion systems, communications etc. ISRO is also responsible for implementation of space segment of GAGAN project.

Indian Institute of Science (IISc) and Indian Institute of Technology (IITs) have successfully collaborated with national and global institutions/companies have the capabilities to do cutting edge multidisciplinary research and technology development besides creating the required pool of technical manpower for the sector.

3.2.2 Private Aerospace Companies
The private aerospace industry in India is mainly concentrated in ‘Design, Engineering & IT solutions’ and ‘Tier-3 manufacturing supplier’ space. With opportunities being created for private sector in defence manufacturing, major industrial houses have entered the field and targeting a larger set of capabilities in the sector through joint ventures with established global and local players who have started sourcing some of their requirements from such companies. Moreover, the Government policy on offsets which requires the vendors to source local input of 30% of the total value in case of defence purchase has created huge opportunities for these companies.

NAL which is entrusted with R&D and aircraft development for the civil aviation has developed capabilities and technologies across the value chain for aerospace development in India. The status of aerospace technological capabilities and products developed by NAL is given in the figure below:

3.3 ANS INFRASTRUCTURE IN INDIA
All the major airports in India have been provided with advanced ATM automation systems. AAI has undertaken projects for restructuring of airspace along with integration of Radars in Chennai FIR (Flight Information Region), and the traffic in the Chennai FIR can now be controlled at Chennai; similar restructuring is planned for all the regions. AAI is installing new radars for optimal radar coverage across the country and once these radars are integrated it will provide contiguous radar coverage leading to enhanced airspace capacity based on radar separation standards as well as an effective redundancy for the radar systems. The radar coverage is being supplemented by installation of ADS-B ground stations which is the new low cost satellite based surveillance technology of the future. ADS-B ground stations have been installed at 21 locations across the country. All major Air Traffic Control Centres at Delhi, Mumbai, Chennai, and Kolkata have been provided with ADS-C/CPDLC which is a satellite based data-link communication system especially useful for control of air traffic in the oceanic and remote areas with limited direct voice communication between controller and pilots.

3.3.1 Performance based Airspace and ATM System; India is implementing Performance Based Navigation (PBN) in a big way. PBN based airspace and ATM lead to enhancement of traffic handling capacity by application of reduced separation, reduced RT congestion (Radio Telephony); Continuous Descent Operations (CDO) and Continuous Climb Operations (CCO). This will lead to reduced fuel burnt carbon emission and reduced noise pollution.
Core Competence

Of NAL spans practically the whole Aerospace Sector[15]
3.3.2 GAGAN (GPS Aided Geo Augmented Navigation) is a satellite based augmentation system (SBAS) for GPS signal developed by AAI in collaboration with ISRO. SBAS technology provides enhanced navigation capability by giving corrected GPS signal to the suitably equipped user over a wide area. GAGAN has been certified for aviation use by DGCA and is 4th of its kind of system after US (WAAS), Europe (EGNOS), and Japan (MSAS). GAGAN will eliminate the need for ground based radio navigation aids which are costly, difficult to maintain, and have limited range. GAGAN will also enable APV (Approach Procedures with Vertical Guidance) approaches similar to Instrument landing system (ILS) and thereby enhancing the safety of operation during the most critical landing phase of the flight. GAGAN will find application in many other areas including in all the other modes of transportation by providing low cost precise positioning service. AAI is also implementing Ground based Augmentation System (GBAS) to further enhance the navigational accuracy of the GNSS/GPS signal in a limited area, which will be used as an alternative to Instrument Landing System (ILS), for precision approaches through GLS (GNSS based Landing System).

3.3.3 Automatic Dependent Surveillance (ADS-B) is yet another next generation space based technology for airspace surveillance wherein an ADS-B (out) equipped aircraft continuously broadcasts its position as determined through GPS/GNSS. These broadcasts are received by suitably located ground stations which can provide the accurate position on real time basis on the Air Traffic Control display, as is received through radars. The existing radar surveillance coverage in India has been enhanced with deployment of 21 ADS-B ground station across country. ADS-B (in) is the futuristic technology where the aircraft would not only be capable of autonomously broadcasting their accurate position but also receive information traffic and other safety related information from the ground stations and other aircraft, which can be used for better air traffic management and enhanced system capacity and efficiency by way of reduced separation standards.
Air Transport is one of the most technology intensive industries; the aviation technologies developed over the years have transformed the human aspirations of mobility and made this world truly flat by destroying distances. The focus of aviation technologies for the future will continue to be on Sustainability, Safety, and Capacity. Aviation is essentially a global industry and therefore technologies are developed and deployed globally. There are number of global initiatives for developing next generation technology solutions being undertaken by European Union, US, and major aerospace manufacturers to address the imminent and future challenges for aviation globally. These technology initiatives have been taken up by Europe and United States to transform their air transport systems and maintain their supremacy in the high end technologies. However, the next generation of technologies would involve global collaboration for an effective management of costs and risks associated with such endeavours. The countries like India with established low cost technological capabilities can play an important role.

4.0
EVOLUTION OF AVIATION TECHNOLOGIES: FUTURE ROADMAP

Air Transport is one of the most technology intensive industry; the aviation technologies developed over the years have transformed the human aspirations of mobility and made this world truly flat by destroying distances. The focus of aviation technologies for the future will continue to be on Sustainability, Safety, and Capacity. Aviation is essentially a global industry and therefore technologies are developed and deployed globally. There are number of global initiatives for developing next generation technology solutions being undertaken by European Union, US, and major aerospace manufacturers to address the imminent and future challenges for aviation globally. These technology initiatives have been taken up by Europe and United States to transform their air transport systems and maintain their supremacy in the high end technologies. However, the next generation of technologies would involve global collaboration for an effective management of costs and risks associated with such endeavours. The countries like India with established low cost technological capabilities can play an important role.

<table>
<thead>
<tr>
<th>Challenges</th>
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<tbody>
<tr>
<td>□ Meeting global expectations for quality, timelines and costs.</td>
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<tr>
<td>□ Shortage of skills, lower productivity levels of the workforce which offsets the low cost labour advantage.</td>
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<tr>
<td>□ Lack of funding and very high interest costs.</td>
</tr>
<tr>
<td>□ Higher taxation for the sector along with disparity between imported aircraft and components/raw material for local production, making any local production uncompetitive.</td>
</tr>
<tr>
<td>□ Dependence on raw material imports, as the size of domestic demand may not justify local production.</td>
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State of the art technology barrier, lack of adequate experience in technology development and commercialization including certification and regulatory approvals.

Unfavourable global technology transfer regime.

Meeting global expectations for quality, timelines and costs.

Lack of funding and very high interest costs.

Dependence on raw material imports, as the size of domestic demand may not justify local production.

Higher taxation for the sector along with disparity between imported aircraft and components/raw material for local production, making any local production uncompetitive.
4.2 GLOBAL FUTURE PERSPECTIVE

Some of the key features of global future Air Traffic Management (ATM) initiatives by Europe (SESAR) and US (NextGen), and ICAO (Global Air Navigation Plan/Aviation System Block Upgrade) for Globally Harmonized ATM Systems and interoperable technology solutions are given below:

- Scalable and Adaptable Airspace system
- System Wide Information Management (SWIM); an information platform for seamless exchange of ATM data and all the other relevant aeronautical and meteorological information in digital form
- SWIM enabled Collaborative Decision Making (CDM); for better predictability and operational efficiency of the system
- 4-D trajectory based Operations
- Performance based Operations
- Digital data-link communication
- GNSS as a primary navigation technology
- Automatic Dependent Surveillance-Broadcast (ADS-B)-out
- Multilateration (MLAT) as surveillance technology along with ADS-B(in)
- Cockpit Display of traffic Information (CDTI)
- Self Spacing and Merging using ADS-B in

The international Air Transport Association (IATA) conducted a study of various aviation technologies for their potential to meet targets of environmentally sustainable air transport in terms of efficiency gains and reduction of emissions. The technologies have been categorized based on the technology readiness levels and compatibility with the existing and next generation aircraft designs. The various aviation technologies presented in the IATA report[13] are illustrated in the figure 4.2.1.

4.3 TECHNOLOGY PRIORITIES FOR INDIA

Objective

- Safe, Sustainable, and Scalable air transport system through deployment of most effective technologies available anywhere in the world
- Enhanced aerospace manufacturing capabilities so as to be a key player in the global aerospace supply chain.
- Design, Development and Certification of a globally competitive regional transport aircraft.

OBJECTIVE:

Consolidation and scaling-up of the existing capabilities to enhance the position in the global aerospace supply chain by effectively leveraging the offset obligations of global OEMs

SHORT TERM (NEXT 5 YEARS)

- Computational Fluid Dynamics (CFD) for design analysis and flow diagnostics
- Sheet metal components, electronic components, cables, wiring, aircraft interiors, seats, upholstery etc.
- Development of advanced materials and composites, including commercialization of technologies developed for local production of raw materials.
- Material characterization and processing
- Structural testing, non-destructive testing
- Drag reduction coatings
- Hydraulic Systems and Landing Gears
- Aero-structures assembly
- Avionics and Flight Control Systems
- Structural health monitoring
- Advanced Manufacturing technologies including machining, castings, forgings, welding, fastening techniques, robotic manufacturing etc.
FIGURE 4.1: FUTURE AVIATION TECHNOLOGIES WITH TIMELINE[13]
### TECHNOLOGY ROADMAP: TRANSPORTATION

<table>
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<tr>
<th>AREA</th>
<th>Focus Areas</th>
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<tr>
<td><strong>ENGINE</strong></td>
<td>Design and development of engine components, materials and subsystems</td>
</tr>
<tr>
<td><strong>FUELS</strong></td>
<td>Development and demonstration of drop-in biofuels and synthetic fuels</td>
</tr>
</tbody>
</table>
| **ANS/AIR TRAFFIC MANAGEMENT**            | • Performance Based Navigation (PBN): Airspace design, reduced separations, continuous climb/descent operations.  
• Collaborative Decision Making (CDM) for enhancement of system capacity, particularly airside surface movement capacity.  
• Satellite based CNS: Data link communications, GNSS/GAGAN for navigation (PBN), ADS-B (OUT) for Surveillance.  
• Central Air Traffic Flow Management System and ATM automation systems with tools as Arrival/Departure Manager (AMAN/DMAN) for optimal utilization of airspace capacity and efficient sequencing of air traffic.  
• Flexible use of airspace (FUA) operations across the country for maximum utilization of airspace by different users.  
• ILS like GAGAN APV approaches.  
• Ground based augmentation and GNSS based landing system (GLS) for ILS CAT-I performance. (ILS CAT I – Instrument Landing System Category 1 is the basic ILS configuration.) |
| **NATIONAL CIVIL TRANSPORT AIRCRAFT FOR REGIONAL CONNECTIVITY** | • Aerospace design and integration capabilities– Technology demonstration for transport aircraft through integration of indigenous as well as the best available technologies across the world. |
| **ICT**                                   | • Framework for integration of air transport into a ICT based multi-modal intelligent transportation network |
| **SKILL DEVELOPMENT & MANUFACTURING TECHNOLOGIES** | • Large scale competitive MRO facilities to harness the business potential of MRO services in India due to location advantage and low cost of labour; and at the same time increase the pool of technically skilled workforce for manufacturing activities. |
| **CERTIFICATION AND SAFETY OVERSIGHT**    | • Enhance the capabilities for certification of components, subsystems and aircrafts. |
OBJECTIVE: Demonstration of commercial aerospace design and manufacturing capabilities and further integration into global aerospace supply chain.

AIRFRAME, SYSTEMS AND MATERIALS

- Complex Aero-structures and Air-frame manufacturing
- Natural laminar flow
- Hybrid laminar flow
- Active load alleviation
- Advanced fly by wire
- Fly by light (Optical fibre)
- Avionics and sensor technologies
- Advanced metallic manufacturing technologies such as pre-forming the raw material into shapes that are close to that of final part
- Additive manufacturing where metal is deposited layer by layer to build up complex shapes
- Laser beam welding and Friction stir welding
- Software based non-destructive structural health monitoring
- New design solutions for the next generation aircraft to be developed around the advanced technologies leading to significant reduction in carbon and noise emissions

ENGINE

- Design and development of indigenous aircraft propulsion system

FUELS AND ALTERNATIVE ENERGY

- Development of next generation energy solutions based on low cost alternative fuels. Alternate energy is the possible area where India should leapfrog by developing cost efficient next generation technology solutions
- The different areas of opportunity within this domain include: Fuels, Engines, Energy storage efficiency, and Energy conversion efficiency
- The products to be focussed besides alternative fuels, new propulsion systems would also include secondary power sources for Auxiliary Power unit (APU), cabin lighting, in-flight entertainment etc.

NATIONAL CIVIL TRANSPORT AIRCRAFT FOR REGIONAL CONNECTIVITY

- Indian Regional Jet with multiple seating configuration for low capacity regional connectivity in tier II and tier III cities
- Equipped with globally latest technologies and materials including composite airframe, structural health monitoring, fly by wire, electrical systems, PBN (Performance Based Navigation), ADS-B (Automatic dependent surveillance – broadcast) etc.
- Capable of all-weather operations, best cabin comfort, fuel efficient, lower emissions and compliant with latest noise standard

ANS/AIR TRAFFIC MANAGEMENT

- Deployment of ADS-B (IN)
- Cockpit Display of Traffic Information (CDTI)
OBJECTIVE:
The long term will be built around the success on the short and medium term priorities, and it is imperative that we design our institutional systems to achieve what we strive for. Next generation airspace system and aerospace supply chain completely integrated with rest of the world.

SOME OF THE AREAS WHICH CAN BE CONSIDERED FOR THE LONG TERM PRIORITIES INCLUDE

- In-trail flight procedures for desired flight level changes for optimum cruise profile
- Reduced separations
- Implementation of next generation ASMGCS [Advanced Surface Movement Guidance and Control System] based on CDTI for self-separation on ground and thereby increasing airport surface movement capacity.
- Deployment of ATM automation systems with decision support functionality and SWIM for efficient management of flight operations and system capacity.
- Deployment of indigenously developed radars and other equipment.
- Advanced nano-modified composites, engineered materials and Carbon nanotubes
- Adaptive materials for better aerodynamics and drag reduction and self-healing properties
- Thermal resistant materials
- Hydrophobic/ice-resistant paints and coatings
- Flame retarding materials
- Electronics and displays with low power consumption multifunctional materials with embedded sensors
- Nanotechnology based synthetic fuels with enhanced properties
- Integrated intermodal transport network based on passenger information system with just-in-time service to reduce the lead time, enhancing system capacity, reducing the travel time, almost real time passenger information being available to the various service providers for an end-to-end travel solution.
- Next generation aircraft designs
- Leadership in alternate energy and fuels
- Next generation manufacturing technologies, use of 3D printing and nanotechnology.
- Next generation propulsion systems based on alternate energy paradigm
- Fuel cells
- Liquid hydrogen as fuel.
- Next Generation avionics and Wireless Flight Control Systems
- System Wide Information Management (SWIM): all data for all relevant flights systematically shared between air and ground systems using SWIM in support of collaborative ATM and trajectory-based operations
- Maturity of ADS-B (IN) and CDTI technologies leading to reduced separation to augment system capacity.
India is uniquely positioned in terms of levers of demand for air transport, sustained economic growth, and almost a clean slate in civil aerospace sector. The global aerospace supply chain is undergoing structural changes due to significant cost pressures and risks involved in high-end technology areas and therefore there is a growing trend towards risk-sharing arrangements in the supply chain along with greater sourcing from low-cost manufacturing countries, which augurs well for India. India with its large talent pool of English speaking engineers, lower costs of production, established software/IT capabilities can ramp-up its aerospace manufacturing capabilities.

Aerospace manufacturing is characterized by very long development cycles and huge development costs, which makes the lack of adequate experience in technology development and commercialization including certification and regulatory approvals even more critical. The success of aerospace development programme will depend upon our ability to address the challenges of adequate pool of right-skilled workforce, access to technologies through global collaboration, long-term clarity on policy and regulatory fronts, strong certification capabilities, access to cheaper raw materials, and a well-developed manufacturing ecosystem capable of supporting such initiatives.

The focus of developing manufacturing capabilities must be export-oriented for integration with global supply chain. Therefore, most important aspect of any aerospace technologies/products to be developed by India should be its global saleability. This would require a strict compliance for quality & timelines and very stringent certification requirements.

5.1 FRAMEWORK FOR AEROSPACE TECHNOLOGY DEVELOPMENT AND MANUFACTURING

Although private participation in technology development and manufacturing is desirable for its efficiencies and management; private sector has limited technological capabilities as of today. Therefore, Government and Public sector will continue to play the major role in technology development and manufacturing till the private sector ecosystem attains a critical size. Even when the private sector ecosystem will mature, the private entities would enter into technology development if it has a strategic advantage and a positive cost/benefit scenario, which limits the private sector to established/proven technologies for product development. Therefore, the framework for aerospace technology and manufacturing needs to focus on private participation in downstream technologies, product development, commercialization public entities in the upstream research and development.

Another important element of this framework is the regulatory and certification regime in the country. Directorate General of Civil Aviation which is the agency responsible for certification of civil aerospace technologies and products would have to proactively engage with the industry to foster innovation and technology development in the country. This would require serious augmentation of manpower and technical capabilities of DGCA through cooperative arrangements with research institutions, industry and global agencies so as to meet the certification challenges for the purpose.

Governments worldover have played a significant role in development of aerospace sector both in the developed and developing countries. Government has already put in place the requirement of ‘Offset’ in all the defence purchases. This policy of Offsets is the most effective strategy for development of local capabilities in the country in view of huge pipeline of government purchase in both military and civil aviation sectors. The potential size of Offset business so created might be much larger than the existing aerospace capacity and therefore effective implementation of the offsets is the key for transformation of aerospace landscape in the country.
The possible strategies for addressing the key challenges in technology development and manufacturing in aerospace sector are discussed below:

5.2 RESEARCH AND DEVELOPMENT

CHALLENGES & TARGETS

Development of core aerospace design and manufacturing technologies in the following areas:

- Airframe design and manufacturing
- Advanced Materials and Composites
- Manufacturing technologies
- Avionics and Flight controls
- Propulsion Systems
- Nanotechnology
- Alternate Fuels
- IT Solutions, Next generation automation products for airline, Airports and ATM

KEY STAKEHOLDER(S)

Government, NAL, HAL, DRDL, BEL, ISRO, academic institutions, Private sector players and SMEs.

IMPLEMENTATION STRATEGY

- Creation of a technology development fund managed by an appropriate autonomous agency. Establishment of an autonomous centre of excellence, drawing up the best of the minds from global industry and academics, as a hub of a broad based network of research institutions to support this technology development fund.

- There should be an assessment and mapping of the existing technological capabilities across different public sector entities and identify critical gaps and areas of opportunity.

- Long term research agenda in consultation with all the stakeholders, having phased targets setting up realistic technology development priorities for the country aligned with the global developments.

- State of the art labs, equipment and testing facilities may be commissioned for utilization on open access basis for supporting technology initiatives in the supply chain.

- Increasing the number of fellowships for specialized studies and PhDs in the area.

- Separate long term national research programmes for developing technologies in the emerging areas like alternate energy and nanotechnology which have wider applications may be instituted for R&D in these areas. The research output and technologies emerging from such programmes can be adopted for product development in aerospace domain.

- Public funding to all the research programmes under this programme. The fund be provided with liberal budgetary support and further funding could be through minor cess on the industry. In the longer run the fund could raise resources through technology spinoffs.

- The technology development programmes must be split into work packages with clear deliverables and timelines. Global collaborations for technology development must be considered under this programme particularly in the areas with state of the art barrier like propulsion systems, avionics, and flight controls etc. as the industry and its supply chain would become truly globalized.

- Licensing some of the core technologies from global OEMs for further development capabilities.

- Effective use of offsets has the potential for transformation of technological capabilities of the industry through technology transfer, joint development.

- Liberal FDI policies in cases where advanced technologies are being brought by the foreign partner. Suitable restrictions can be imposed on award of offset contract to such Joint Ventures.

- The R&D institutions may be supported to undertake research projects from the global initiatives for development of next generation technologies.
5.3 PRODUCT/TECHNOLOGY DEVELOPMENT ACROSS AEROSPACE VALUE CHAIN

CHALLENGES & TARGETS
Scaling up the technological capabilities of India aerospace companies to move up the value chain for developing aero-structures, components and Line Replaceable Units (LRUs). Areas which may be considered:

- Engineering and Design
- Software and IT solutions
- Aerostructures manufacturing
- Non-destructive Structural Health Monitoring
- Composites
- Avionics
- Alternate Energy and bio-fuels

Creation of a broad based manufacturing ecosystem for aerospace manufacturing.

Domestic production of key raw materials including composites, aluminium and titanium and other specialty alloys for aerospace applications including missiles, weapons systems, aircrafts and space applications. Today all the raw material is imported.

KEY STAKEHOLDER(S)
Private Industry, Public entities like HAL, NAL, DRDL, ISRO, Metal companies, academic institutions, Global aerospace majors.

IMPLEMENTATION STRATEGY

- Promoting private participation in all the existing projects being executed by HAL, so as to foster development of private enterprises/ SMEs and enable them to move higher in the value chain. HAL must outsource more of the low end manufacturing to private players and SMEs along with the required technology support and handholding.

- Effective management and compliance of offset requirement for creating the capacities, co-development of products. Similar Offset policies for civil aerospace purchases and synergies between offsets across the contracts need to be implemented.

- New projects for product development by Government agencies must be executed under PPP mode. Such PPP projects once sustainable may be completely privatized to scout for global opportunities.

- Promoting technology licensing/spinoffs and joint product development by the public sector entities with private sector partners.

- Product/technology development in academic institutions through collaborative/ sponsored research.

- Technological capabilities through acquisitions of smaller/specialized aerospace technology companies abroad.

- Sharing of labs, equipments and testing facilities created in the public sector at minimal costs.

- Government funding for technology upgradation of SMEs could also be considered either directly or through fiscal incentives.

- Transfer of technology for composites and other advanced materials by the public entities to private companies for large scale production. Innovation in the manufacturing processes is must to reduce the cost. Large industrial houses are who are already into composites can be roped in.
5.4 NATIONAL CIVIL AIRCRAFT (NCA)

CHALLENGES & TARGETS

Development of a Civil Transport Aircraft in the Regional Jet Category for regional connectivity in tier II and tier III cities with:

- Equipped with latest technologies and materials including composite airframe, structural health monitoring, fly by wire, electrical systems, PBN, ADS-B, Turboprop and Turbo fan variants, Multiple seating configuration (below 100 seats)
- Capable of all-weather operations, best cabin comfort, Low emissions and compliant with latest noise standard
- Low cost of acquisition, operation and maintenance

Global Experience/Challenges

The experience of the other developing countries like Brazil and China suggests that such capabilities require decade’s hard work in migrating from component manufacturing to aero-structures, then manufacturing small planes, licensed production for other companies before making it big.

China even with its resources, manufacturing capabilities, faster decision making is yet to get success on its domestic aircraft programme in about 30 years. This is a clear indication of the size of challenge involved and therefore requires unrelenting efforts and strategy in order to be successful.

Critical Gaps/Risks

- Lack of experience in execution of such projects, marketing strategies, customer support, training, maintenance and lifecycle upgrades.
- Lack of reliable technologies like propulsion system, avionics and flight controls.

KEY STAKEHOLDER(S)


IMPLEMENTATION STRATEGY

- The project must be instituted as an independent entity under the Ministry of Civil Aviation, drawing expertise from across the aerospace spectrum in the country.
- The project must be executed in Public Private Partnership (PPP) mode with carefully selected consortium of private sector partners and preferably a global OEM having experience in aircraft manufacturing, running such large and complex project, marketing and customer support.
- The project entity should have independent subsidiaries for different areas of aircraft manufacturing like airframe, propulsion, avionics and flight controls to be set up as PPP with NAL, HAL and BEL as the key public sector partners and global OEM as a partner.
- The decision on “make or buy” on critical technologies must be based on the assessment of available technology in the country, possibility of joint development with global OEMs, technology development cost and time estimates. The areas like propulsion system, avionics and flight controls in which reliable technology is not available and cannot be developed within a timeframe and cost should be bought from outside.
- The project must have an export orientation right at the conceptual stage and be designed to meet or better the contemporary global specifications in terms of efficiency, performance and life cycle costs to be successful in the market.
- The project must be aggressively marketed and should have launch customers to support the development and reduce uncertainties.
- The private sector industry partners must adopt a consortium model to involve SME vendors already available in the country; vendor development for different components can be taken up from established automotive sector.
- Government should fund the development costs and could be one of the launch customers; low cost funding must be made available for the project.
- Public infrastructure in terms of R&D labs, equipment, testing facilities, and other infrastructure must be shared at a nominal cost to keep the cost of project down.
- Joint development with some other country can also be considered to de-risk the project.
5.5 ANS TECHNOLOGIES/INFRASTRUCTURE

CHALLENGES & TARGETS
Airspace congestion, growing demand for air transport.
Huge investment required in ANS infrastructure.

KEY STAKEHOLDER(S)
Airports Authority of India (AAI), IT Industry

IMPLEMENTATION STRATEGY
- ANS technologies to be adopted in line with global and regional plans for up-gradation and harmonization of ANS infrastructure in the region.
- India with a very large and high growth aviation market should take a leadership role in implementation of latest ANS technologies in this region.
- Government funding through budgetary support and/or soft loans be provided for deployment of ANS technologies.
- A long term plan for development/deployment of ANS technology modules must be prepared and shared with Indian software and aerospace industry by Airports Authority of India (AAI). This will provide an opportunity for Indian technology companies to develop capabilities and products in this area.

5.6 HUMAN RESOURCE - SKILL DEVELOPMENT

CHALLENGES & TARGETS
Shortage of the required skill sets is the single most critical challenge for the industry. To create a large pool of skilled workforce across the value chain of the aviation industry.

KEY STAKEHOLDER(S)
Government, Academic & Training institutions and Industry

IMPLEMENTATION STRATEGY
- Scaling up the capacity of existing academic institutions with specialized industry engineering courses.
- Scaling up training capacity for Pilots, Air traffic controllers (ATC), Aircraft maintenance engineers (AME), and other professionals for the air transport industry, and streamlining the certification/licensing process.
- Focus on vocational education in schools, followed by industry apprentice programmes.
- Specialized industrial training institutes (ITIs) to be established in the manufacturing clusters under PPP.
- Government support for training/apprentice programmes of individual companies to ensure that the relevant skills are created.
- Migration of skilled labour from auto ancillary sector to aerospace could be also considered in the short term, which is otherwise also normal in the course of labour market churn.
- Training and skill upgradation could be considered under the offset contracts in a limited way for certain specialized skills so as to quickly ramp-up.
Mobility has played a key role in the development of human race on this planet, and invention of wheel is perhaps one of the most enduring discoveries of all the time in the history of mankind. Transportation networks are a key enabler for the trade between modern day economies with large scale production and distribution of goods and services across the different regions. The different modes of transportation have evolved over the years with technologies making it more and more efficient in terms of costs as well as speed. The different modes of transportation have their own advantages and even have competition for the share of passenger and cargo traffic; however there is no reason to promote any particular mode at the cost of the other; This realization is reflected in the emerging thrust on seamless multi-modal transportation system capable of moving the passengers and goods in the most efficient manner; and providing efficient choices to the consumer to select the best combination on the basis of individual needs.

Aviation technologies developed over the years have transformed the human aspirations of mobility and made this world truly flat by minimising distances. The need for an efficient air transport network and its role in transformation of economy through integration...
Air transport has significant socioeconomic contribution in integrating the remote areas like Northeast, Andaman & Lakshadweep Islands with the mainland. The connectivity to these areas is not only important for development of these regions, but also for the security situation in country as these regions mostly happen to be along international borders and facing the dangers of terrorism and insurgency. Moreover, some of these areas frequently face natural disasters. An effective air transport network is crucial for disaster management and relief measures. Air transport plays a very crucial role in promoting tourism sector which contributes significantly to the national economy as well as the creation of jobs in the economy. A recent study by Oxford Economics has estimated the contribution of aviation to the India’s GDP as 0.5% on standalone basis, and 1.5% including the catalytic impact through tourism. The study also estimates jobs supported by aviation to be 1.7 million and an additional 7.1 million jobs through the catalytic impact on tourism. It is also emphasized that the jobs in air transport sector are estimated to be around 10 times more productive than the average.

The demand for air transport in India has been growing at a phenomenal rate in the last decade which has made India the 9th largest aviation market in the world, and this growth is likely to continue for next few decades and India is expected to become 3rd largest aviation market in the world by 2020. The way demographics are positioned, India with a younger population will be one of the key suppliers of the workforce to the ageing countries in the West both in the onshore and offshore modes. Air transport is therefore one of the most crucial infrastructures for success in all such economic activities.

The growth in aviation has thrown a lot of challenges and opportunities for India, and huge investments are required in the infrastructure and deployment of advanced technologies to sustain this growth of aviation and its consequent impact on the rest of the economy. The most immediate imperative is to address the issues of capacity constraints in the Air Transport System which require significant investments for upgradation of Air Navigation Services (ANS) and airport infrastructure in the country.

ICAO has instituted a Global Air Navigation Plan for a globally harmonized deployment of aviation technologies in order to ensure interoperability across regions. ICAO has adopted ASBU (Aviation System Block Upgrades) which proposes frame work for modular implementation of system upgrades around the existing and emerging aviation technologies, along with the required changes in the regulatory standards and operational procedures as an integrated module for a defined operational improvement.

India has embarked upon a serious technology drive to upgrade its ANS infrastructure and technologies and has made significant progress in implementation of PBN (Performance Based Navigation), enhanced surveillance through deployment of ADS-B, reduced separation requirements in performance based airspace, Flexible use of Airspace (FUA) for civil and military purpose. However, the progress made so far may not be sufficient to address the future challenges in terms of system capacity and ever growing demand scenarios which are specific to India. Therefore, India will have to create a robust strategic roadmap for ANS infrastructure in the country backed up by adequate financial resources in order to create an air transport system capable of meeting the demands of different air space users. The financial commitments for such initiative needs be understood in the context of economy. The aerospace industry in the country is heavily skewed towards the public sector entities like HAL, DRDL, and NAL which is a result of the government policy to keep this sector reserved
for public sector prior to year 2001. HAL has created significant capacities for aircraft manufacturing for defence; however, there has not been much of success on the civil front. The private industry evolved in a limited way to supply components to HAL for its licensed manufacturing projects. After 2001 when the sector was opened for private players, the private industry has made some progress in providing software/engineering services to the global aerospace majors, but did not build a robust capability for technology development and commercialization. An effective implementation of the offset policy can play a key role for kick starting the transformation of aerospace landscape in the country.

RECOMMENDATIONS

7.1 Air Traffic Management
i. There should be a systematic up-gradation of ANS infrastructure in the country for improvement in the operational efficiency of the air transport system through deployment of CNS/ATM technologies and design of airspace and operational procedures around the existing and emerging airborne technologies. This endeavour is expected to yield significant improvement in the system capacity along with reduction in fuel burnt, carbon and noise emission through effective utilization of the capabilities of modern day aircraft.

ii. A long term plan for development/deployment of CNS/ATM technology modules must be prepared and shared with Indian software and aerospace industry by AAI. This will provide an opportunity for Indian technology companies to develop capabilities and products in this area.

7.2 Research and Technology Development
i. Set up an autonomous technology development fund for public funding of R&D programmes across the value chain on the basis of a long term research agenda for developing next generation aerospace technologies for aircraft manufacturing in the country. An autonomous centre of excellence may be created as a hub of a broad based network of research institutions to support this technology development fund. This technology development fund may be provided with liberal budgetary support. In the longer run the fund could also raise resources through technology spinoffs and licensing arrangements.

ii. State of the art labs, equipment and testing facilities may be commissioned for utilization on open access basis. Existing public infrastructure in terms of R&D labs, equipment, testing facilities, and other infrastructure may be shared with private sector at a nominal cost to support product development and aerospace supply chain.

iii. The technology development programmes should have work packages with clear deliverables and timelines keeping the interdependencies of various stakeholders in mind. R&D work packages for all new projects to be awarded under competitive bidding to the best player public or private, with strict performance requirements and milestones. A long term technology development programme may be instituted for development of critical aircraft propulsion technologies in the country.

iv. Separate long term national research programmes may be instituted for developing technologies in the emerging areas like ‘alternate energy’ and ‘nanotechnology’ which have wider applications across different areas.

7.3 Product Development and Manufacturing
i. All the new public sector projects for product development in the supply chain may be executed under PPP mode for developing a broad-based supply chain in the country. Such projects once sustainable may be completely privatized to scout for global opportunities.

ii. Labour intensive Maintenance, Repair and Overhaul (MRO) industry may be given suitable fiscal incentives to realize the huge business opportunity in the sector and also for creating a pool of skilled workforce for aerospace manufacturing.

iii. Government funded skill development and training across the spectrum of skill-sets required for aerospace manufacturing may be instituted.
iv. Transfer of technology for composites and other advanced materials by the public sector entities to private companies for large scale production of raw materials may be considered. Large industrial houses are who are already into composites may be roped in.

v. Offset policy for civil aerospace purchases may also be considered. A national plan aligned with the technology agenda may be instituted for creating capacities through co-development of products and technology transfers under the offset requirements and there should be synergies between offsets across the contracts.

vi. Government funding for technology upgradation of SMEs in the sector may also be considered either directly or through fiscal incentives in order to enable SMEs to make the best use of opportunities created by the offset policy.

vii. Strengthen the certification and regulatory systems in the country through augmentation of manpower and technical capabilities of DGCA. This can be achieved through cooperative arrangements with research institutions, industry and global agencies in the field. There should be bilateral agreements with US and EU for mutual acceptance of certification in order to strengthen the role of Indian vendors in global supply chain.

7.4 National Civil Transport Aircraft

i. The proposed National Civil Aircraft project may be put on fast track and may be executed in PPP mode with carefully selected private sector partners including global OEMs having required experience in execution of such projects along with establishing market strategies, customer support, training, maintenance and lifecycle upgrades that market will demand.

ii. The project must have an export orientation right at the conceptual stage and be designed to meet or better the contemporary global specifications in terms of efficiency, performance and life cycle costs to be successful in the market. The aircraft should be equipped with the most advanced technologies available and meet the global specifications and marketed globally.

iii. The decision on “make or buy” on critical technologies must be based on the assessment of available technology in the country, possibility of joint development with global OEMs, technology development cost and time estimates. The areas like propulsion system, avionics and flight controls in which reliable technology is not available and cannot be developed within a timeframe and should be bought from outside.
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