Chapter 1
Introduction to transportation engineering

1.1 Overview

Mobility is a basic human need. From the times immemorial, everyone travels either for food or leisure. A closely associated need is the transport of raw materials to a manufacturing unit or finished goods for consumption. Transportation fulfills these basic needs of humanity. Transportation plays a major role in the development of the human civilization. For instance, one could easily observe the strong correlation between the evolution of human settlement and the proximity of transport facilities. Also, there is a strong correlation between the quality of transport facilities and standard of living, because of which society places a great expectation from transportation facilities. In other words, the solution to transportation problems must be analytically based, economically sound, socially credible, environmentally sensitive, practically acceptable and sustainable. Alternatively, the transportation solution should be safe, rapid, comfortable, convenient, economical, and eco friendly for both men and material.

1.2 Transportation system

In the last couple of decades transportation systems analysis has emerged as a recognized profession. More and more government organizations, universities, researchers, consultants, and private industrial groups around the world are becoming truly multi-modal in their orientation and are opting a systematic approach to transportation problems.

1.2.1 Diverse characteristics

The characteristics of transportation system that makes it diverse and complex are listed below:

1. Multi-modal: Covering all modes of transport; air, land, and sea for both passenger and freight.
2. Multi-sector: Encompassing the problems and viewpoints of government, private industry, and public.
3. Multi-problem: Ranging across a spectrum of issues that includes national and international policy, planning of regional system, the location and design of specific facilities, carrier management issues, and regulatory, institutional and financial policies.
4. Multi-objective: Aiming at national and regional economic development, urban development, environment quality, and social quality, as well as service to users and financial and economic feasibility.
5. Multi-disciplinary: Drawing on the theories and methods of engineering, economics, operations research, political science, psychology, other natural, and social sciences, management and law.

1.2.2 Study context

The context in which transportation system is studied is also very diverse and are mentioned below:

1. Planning range: Urban transportation planning, producing long range plans for 5-25 years for multimodal transportation systems in urban areas as well as short range programs of action for less than five years.
2. Passenger transport: Regional passenger transportation, dealing with inter-city passenger transport by air, rail, and highway and possible with new modes.
3. Freight transport: Routing and management, choice of different modes of rail and truck.
4. International transport: Issues such as containerization, inter-modal co-ordination.

1.2.3 Background: A changing world

The strong interrelationship and the interaction between transportation and the rest of the society especially in a rapidly changing world is significant to a transportation planner. Among them four critical dimensions of change in transportation system can be identified; which form the background to develop a right perspective.

1. Change in the demand: When the population, income, and land-use pattern changes, the pattern of demand changes; both in the amount and spatial distribution of that demand.
2. Changes in the technology: As an example, earlier, only two alternatives (bus transit and rail transit) were considered for urban transportation.
3. Change in operational policy: Variety of policy options designed to improve the efficiency, such as incentive for car-pooling, bus fare, road tolls etc.
4. Change in values of the public: Earlier all beneficiaries of a system was monolithically considered as users. Now, not one system can be beneficial to all, instead one must identify the target groups like rich, poor, young, work trip, leisure etc.

1.2.4 Role of transportation engineer

In spite of the diversity of problem types, institutional contexts and technical perspectives there is an underlying unity: a body of theory and set of basic principles to be utilized in every analysis of transportation systems. The core of this is the transportation system analysis approach. The focus of this is the interaction between the transportation and activity systems of region. This approach is to intervene, delicately and deliberately in the complex fabric of society to use transport effectively in coordination with other public and private actions to achieve the goals of that society. For this the analyst must have substantial understanding of the transportation

1.3 Major disciplines of transportation

Transportation engineering can be broadly consisting of the four major parts:

1. Transportation Planning
2. Geometric Design
3. Pavement Design
4. Traffic Engineering

A brief overview of the topics is given below: Transportation planning deals with the development of a comprehensive set of action plan for the design, construction and operation of transportation facilities.

1.3.1 Transportation planning

Transportation planning essentially involves the development of a transport model which will accurately represent both the current as well as future transportation system.

1.3.2 Geometric design

Geometric design deals with physical proportioning of other transportation facilities, in contrast with the structural design of the facilities. The topics include the cross-sectional features, horizontal alignment, vertical alignment and intersections. Although there are several modes of travel like road, rail, air, etc.. the underlying principles are common to a great extent. Therefore emphasis will be normally given for the geometric design of roads.

1.3.3 Pavement analysis and design

Pavement design deals with the structural design of roads, both (bituminous and concrete), commonly known as(flexible pavements and rigid pavements) respectively. It deals with the design of paving materials, determination of the layer thickness, and construction and maintenance procedures. The design mainly covers structural aspects, functional aspects, drainage. Structural design ensures the pavement has enough strength to withstand the impact of loads, functional design emphasizes on the riding quality, and the drainage design protects the pavement from damage due to water infiltration.

1.3.4 Traffic engineering

Traffic engineering covers a broad range of engineering applications with a focus on the safety of the public, the efficient use of transportation resources, and the mobility of people and goods. Traffic engineering involves a variety of engineering and management skills, including design, operation, and system optimization. In order to address the above requirement, the traffic engineer must first understand the traffic row behavior and characteristics by extensive collection of traffic row data and analysis. Based on this analysis, traffic row is controlled so that the transport infrastructure is used optimally as well as with good service quality. In short, the role of traffic engineer is to protect the environment while providing mobility , to preserve scarce resources while assuring economic activity, and to assure safety and security to people and vehicles, through both acceptable practices and high-tech communications.

1.4 Other important disciplines

In addition to the four major disciplines of transportation, there are several other important disciplines that are being evolved in the past few decades. Although it is difficult to categorize them into separate well designed disciplines because of the significant overlap, it may be worth the effort to highlight the importance given by the transportation community. They can be enumerated as below:

1. Public transportation: Public transportation or mass transportation deals with study of the transportation system that meets the travel need of several people by sharing a vehicle. Generally this focuses
on the urban travel by bus and rail transit. The major topics include characteristics of various modes; planning, management and operations; and policies for promoting public transportation.

2. Financial and economic analysis Transportation facilities require large capital investments. Therefore it is imperative that whoever invests money should get the returns. When government invests in transportation, its objective is not often monetary returns; but social benefits. The economic analysis of transportation project tries to quantify the economic benefit which includes saving in travel time, fuel consumption, etc. This will help the planner in evaluating various projects and to optimally allocate funds. On the contrary, private sector investments require monetary profits from the projects. Financial evaluation tries to quantify the return from a project.

3. Environmental impact assessment the depletion of fossil fuels and the degradation of the environment has been a severe concern of the planners in the past few decades. Transportation; in spite of its benefits to the society is a major contributor to the above concern. The environmental impact assessment attempts in quantifying the environmental impacts and tries to evolve strategies for the mitigation and reduction of the impact due to both construction and operation. The primary impacts are fuel consumption, air pollution, and noise pollution.

4. Accident analysis and reduction one of the silent killers of humanity is transportation. several statistics evaluates that more people are killed due to transportation than great wars and natural disasters. This discipline of transportation looks at the causes of accidents, from the perspective of human, road, and vehicle and formulates plans for the reduction.

5. Intelligent transport system with advent to computers, communication, and vehicle technology, it is possible in these days to operate transportation system much effectively with significant reduction in the adverse impacts of transportation. Intelligent transportation system others better mobility, efficiency, and safety with the help of the state-of-the-art-technology. In addition disciplines specific to various modes are also common. This includes railway engineering, port and harbor engineering, and airport engineering.

Chapter 2

Introduction to Highway Engineering

2.1 Overview

Road transport is one of the most common mode of transport. Roads in the form of track ways, human pathways etc. were used even from the pre-historic times. Since then many experiments were going on to make the riding safe and comfort. Thus road construction became an inseparable part of many civilizations and empires. In this chapter we will see the different generations of road and their characteristic features. Also we will discuss about the highway planning in India.

2.2 History of highway engineering

The history of highway engineering gives us an idea about the roads of ancient times. Roads in Rome were constructed in a large scale and it radiated in many directions helping them in military operations. Thus they are considered to be pioneers in road construction. In this section we will see in detail about Ancient roads, Roman roads, British roads, French roads etc.

2.2.1 Ancient Roads

The first mode of transport was by foot. These human pathways would have been developed for specific purposes leading to camp sites, food, streams for drinking water etc. The next major mode of transport was the use of animals for transporting both men and materials. Since these loaded animals required more horizontal and vertical clearances than the walking man, track ways emerged. The invention of wheel in Mesopotamian civilization led to the development of animal drawn vehicles. Then it became necessary that the road surface should be capable of carrying greater loads. Thus roads with harder surfaces emerged. To provide adequate strength to carry the wheels, the new ways tended to follow the sunny drier side of a path. These have led to the development of foot-paths. After the invention of wheel, animal drawn vehicles were developed and the need for hard surface road emerged. Traces of such hard roads were obtained from various ancient civilization dated as old as 3500 BC. The earliest authentic record of road was found from Assyrian empire constructed about 1900 BC.

2.2.2 Roman roads

The earliest large scale road construction is attributed to Romans who constructed an extensive system of roads radiating in many directions from Rome. They were a remarkable achievement and provided travel times across Europe, Asia minor, and north Africa. Romans recognized that the fundamentals of good road construction were to provide good drainage, good material and good workmanship. Their roads were very durable, and some are still existing. Roman roads were always constructed on a firm - formed sub grade strengthened where necessary with wooden piles. The roads were bordered on both sides by longitudinal drains. The next step was the construction of the agger. This was a raised formation up to a 1 meter high and 15 m wide and was constructed with materials excavated during the side drain construction. This was then topped with a sand leveling course. The agger contributed greatly to moisture control in the pavement. The pavement structure on the top of the agger varied greatly. In the case of heavy traffic, a surface course of large 250 mm thick hexagonal flag stones were provided. The main features of the Roman roads are that they were built straight regardless of gradient and used heavy foundation stones at the bottom. They mixed lime and volcanic puzzolana to make mortar and they added gravel to this mortar to make concrete. Thus concrete was a major Roman road making innovation.

2.2.3 French roads

The next major development in the road construction occurred during the regime of Napoleon. The significant contributions were given by Tresaguet in 1764. He developed a cheaper method of construction than the lavish and locally unsuccessful revival of Roman practice. The pavement used 200 mm pieces of quarried stone of a more compact form and shaped such that they had at least one flat side which was placed on a compact formation. Smaller pieces of broken stones were then compacted into the spaces between larger stones to provide a level surface. Finally the running layer was made with a layer of 25 mm sized broken stone. All this structure was placed in a trench in order to keep the running surface level with the surrounding country side. This created major drainage problems which were counteracted by making the surface as impervious as possible, cambering the surface and providing deep side ditches. He gave much importance for drainage. He also enunciated the necessity for continuous organized maintenance, instead of intermittent repairs if the roads were to be kept usable all times. For this he divided the roads between villages into sections of such length that an entire road could be covered by maintenance men living nearby.

2.2.4 British roads

The British government also gave importance to road construction. The British engineer John Macadam introduced what can be considered as the first scientific road construction method. Stone size was an important element of Macadam recipe. By empirical observation of many roads, he came to realize that 250 mm layers of well compacted broken angular stone would provide the same strength and stiffness and a better running surface than an expensive pavement founded on large stone blocks. Thus he introduced an economical method of road construction.

The mechanical interlock between the individual stone pieces provided strength and stiffness to the course. But the inter particle friction abraded the sharp interlocking faces and partly destroy the effectiveness of the course. This effect was overcome by introducing good quality interstitial finer material to produce a well-graded mix. Such mixes also proved less permeable and easier to compact.

2.2.5 Modern roads

The modern roads by and large follow Macadam’s construction method. Use of bituminous concrete and cement concrete are the most important developments. Various advanced and cost-effective construction technologies are used. Development of new equipments help in the faster construction of roads. Many easily and locally available materials are tested in the laboratories and then implemented on roads for making economical and durable pavements. Scope of transportation system has developed very largely. Population of the country is increasing day by day. The life style of people began to change. The need for travel to various places at faster speeds also increased. This increasing demand led to the emergence of other modes of transportation like railways and travel by air. While the above development in public transport sector was taking place, the development in private transport was at a much faster rate mainly because of its advantages like accessibility, privacy, flexibility, convenience and comfort. This led to the increase in vehicular traffic especially in private transport network. Thus road space available was becoming insufficient to meet the growing demand of traffic and congestion started. In addition, chances for accidents also increased. This has led to the increased attention towards control of vehicles so that the transport infrastructure was optimally used. Various control measures like traffic signals, providing roundabouts and medians, limiting the speed of vehicle at specific zones etc. were implemented. With the advancement of better roads and efficient control, more and more investments were made in the road sector especially after the World wars. These were large projects requiring large investment. For optimal utilization of funds, one should know the travel pattern and travel behavior. This has led to the emergence of transportation planning and demand management.

2.3 Highway planning in India

Excavations in the sites of Indus valley, Mohenjo-Daro and Harappan civilizations revealed the existence of planned roads in India as old as 2500-3500 BC. The Mauryan kings also built very good roads. Ancient books like Arthashastra written by Kautilya, a great administrator of the Mauryan times, contained rules for regulating traffic, depths of roads for various purposes, and punishments for obstructing traffic. During the time of Mughal period, roads in India were greatly improved. Roads linking North-West and the Eastern areas through gangetic plains were built during this time. After the fall of the Mughals and at the beginning of British rule, many existing roads were improved. The construction of Grand-Trunk road connecting North and South is a major contribution of the British. However, the focus was later shifted to railways, except for feeder roads to important stations.

2.3.1 Modern developments

The first World war period and that immediately following it found a rapid growth in motor transport. So need for better roads became a necessity. For that, the Government of India appointed a committee called Road development Committee with Mr.M.R. Jayakar as the chairman. This committee came to be known as Jayakarcommittee.

Jayakar Committee

In 1927 Jayakar committee for Indian road development was appointed. The major recommendations and the resulting implementations were:

- Committee found that the road development of the country has become beyond the capacity of local governments and suggested that Central government should take the proper charge considering it as a matter of national interest.
- They gave more stress on long term planning programme, for a period of 20 years (hence called twenty-year plan) that is to formulate plans and implement those plans with in the next 20 years.
- One of the recommendations was the holding of periodic road conferences to discuss about road construction and development. This paved the way for the establishment of a semi-official technical body called Indian Road Congress (IRC) in 1934
- The committee suggested imposition of additional taxation on motor transport which includes duty on motor spirit, vehicle taxation, license fees for vehicles plying for hire. This led to the introduction of development fund called Central road fund in 1929. This fund was intended for road development.
- A dedicated research organization should be constituted to carry out research and development work. This resulted in the formation of Central Road Research Institute (CRRI) in 1950.

Nagpur road congress 1943. The second World War saw a rapid growth in road traffic and this led to the deterioration in the condition of roads. To discuss about improving the condition of roads, the government convened a conference of chief engineers of provinces at Nagpur in 1943. The result of the conference is famous as the Nagpur plan.

- A twenty year development programme for the period (1943-1963) was finalized. It was the first attempt to prepare a co-ordinate road development programme in a planned manner.

• The roads were divided into four classes:
– National highways which would pass through states, and places having national importance for strategic, administrative and other purposes.
– State highways which would be the other main roads of a state.
– District roads which would take traffic from the main roads to the interior of the district . According to the importance, some are considered as major district roads and the remaining as other district roads.
– Village roads which would link the villages to the road system.
• The committee planned to construct 2 lakh kms of road across the country within 20 years.
• They recommended the construction of star and grid pattern of roads throughout the country.
• One of the objective was that the road length should be increased so as to give a road density of 16kms per 100 sq.km

Bombay road congress 1961

The length of roads envisaged under the Nagpur plan was achieved by the end of it, but the road system was deficient in many respects. The changed economic, industrial and agricultural conditions in the country warranted a review of the Nagpur plan. Accordingly a 20-year plan was drafted by the Roads wing of Government of India, which is popularly known as the Bombay plan. The highlights of the plan were:
• It was the second 20 year road plan (1961-1981)
• The total road length targeted to construct was about 10 lakhs.
• Rural roads were given specific attention. Scientific methods of construction was proposed for the rural roads. The necessary technical advice to the Panchayaths should be given by State PWD's.
• They suggested that the length of the road should be increased so as to give a road density of 32kms/100sq.km
• The construction of 1600 km of expressways was also then included in the plan.

Lucknow road congress 1984

This plan has been prepared keeping in view the growth pattern envisaged in various fields by the turn of the century. Some of the salient features of this plan are as given below:
• This was the third 20 year road plan (1981-2001). It is also called Lucknow road plan.
• It aimed at constructing a road length of 12 lakh kilometers by the year 1981 resulting in a road density of 82kms/100 sq.km
• The plan has set the target length of NH to be completed by the end of seventh, eighth and ninth five-year plan periods.
• It aims at improving the transportation facilities in villages, towns etc. such that no part of country is farther than 50 km from NH.
• One of the goals contained in the plan was that expressways should be constructed on major traffic corridors to provide speedy travel.

Chapter 3

Role of transportation in society

3.1 Overview

Transportation is a non separable part of any society. It exhibits a very close relation to the style of life, the range and location of activities and the goods and services which will be available for consumption. Advances in transportation has made possible changes in the way of living and the way in which societies are organized and therefore have a great influence in the development of civilizations. This chapter conveys an understanding of the importance of transportation in the modern society by presenting selected characteristics of existing transportation systems, their use and relationships to other human activities. Transportation is responsible for the development of civilizations from very old times by meeting travel requirement of people and transport requirement of goods. Such movement has changed the way people live and travel. In developed and developing nations, a large fraction of people travel daily for work, shopping and social reasons. But transport also consumes a lot of resources like time, fuel, materials and land.

3.2 Economic role of transportation

Economics involves production, distribution and consumption of goods and services. People depend upon the natural resources to satisfy the needs of life but due to non uniform surface of earth and due to difference in local resources, there is a lot of difference in standard of living in different societies. So there is an immense requirement of transport of resources from one particular society to other. These resources can range from material things to knowledge and skills like movement of doctors and technicians to the places where there is need of them.

3.2.1 The place, time, quality and utility of goods

An example is given to evaluate the relationship between place, time and cost of a particular commodity. If a commodity is produced at point A and wanted by people of another community at any point B distant x from A, then the price of the commodity is dependent on the distance between two centers and the system of transportation between two points. With improved system the commodity will be made less costly at B.

3.2.2 Changes in location of activities

The reduction of cost of transport does not have same effect on all locations. Let at any point B the commodity is to be consumed. This product is supplied by two stations A and K which are at two different distances from B. Let at present the commodity is supplied by A since it is at a lesser distance but after wards due to improvement in road network between B and K,the point K becomes the supply point of product.

3.2.3 Conclusions

• Transport extends the range of sources of supply of goods to be consumed in an area, making it possible for user to get resources at cheap price and high quality.

• The use of more efficient systems of supply results in an increase in the total amount of goods available for consumption.

• Since the supply of goods is no longer dependent on the type of mode, items can be supplied by some alternative resources if usual source cannot supply what is needed.

3.3 Social role of transportation

Transportation has always played an important role in influencing the formation of urban societies. Although other facilities like availability of food and water, played a major role, the contribution of transportation can be seen clearly from the formation, size and pattern, and the development of societies, especially urban centers.

3.3.1 Formation of settlements

From the beginning of civilization, the man is living in settlements which existed near banks of major river junctions, a port, or an intersection of trade routes. Cities like New York, Mumbai and Moscow are good examples.

3.3.2 Size and pattern of settlements

The initial settlements were relatively small developments but with due course of time, they grew in population and developed into big cities and major trade centers. The size of settlements is not only limited by the size of the area by which the settlement can obtain food and other necessities, but also by considerations of personal travels especially the journey to and from work. The increased speed of transport and reduction in the cost of transport have resulted in variety of spatial patterns.

3.3.3 Growth of urban centers

When the cities grow beyond normal walking distance, then transportation technology plays a role in the formation of the city. For example, many cities in the plains developed as a circular city with radial routes, where as the cities beside a river developed linearly. The development of automobiles, and other factors like increase in personal income, and construction of paved road network, the settlements were transformed into urban centers of intense travel activity.

3.4 Political role of transportation

The world is divided into numerous political units which are formed for mutual protection, economic advantages and development of common culture. Transportation plays an important role in the functioning of such political

3.4.1 Administration of an area

The government of an area must be able to send/get information to/about its people. It may include laws to be followed, security and other needful information needed to generate awareness. An efficient administration of a country largely depends on how effectively government could communicate these information to all the country. However, with the advent of communications, its importance is slightly reduced.

3.4.2 Political choices in transport

These choices may be classified as communication, military movement, travel of persons and movement of freight. The primary function of transportation is the transfer of messages and information. It is also needed for rapid movement of troops in case of emergency and finally movement of persons and goods. The political decision of construction and maintenance of roads has resulted in the development of transportation system.

3.5 Environmental role of transportation

The negative effects of transportation is more dominating than its useful aspects as far as transportation is concerned. There are numerous categories into which the environmental effects have been categorized. They are explained in the following sections.

3.5.1 Safety

Growth of transportation has a very unfortunate impact on the society in terms of accidents. Worldwide death and injuries from road accidents have reached epidemic proportions. -killed and about 15 million injured on the road accidents annually. Increased variation in the speeds and vehicle density resulted in a high exposure to accidents. Accidents result in loss of life and permanent disability, injury, and damage to property. Accidents also causes numerous non-quantifiable impacts like loss of time, grief to the near ones of the victim, and inconvenience to the public. The loss of life and damage from natural disasters, industrial accidents, or epidemic often receive significant attention from both government and public. This is because their occurrence is concentrated but sparse. On the other hand, accidents from transport sector are widespread and occurs with high frequency. For instance, a study has predicted that death and disabilities resulting from road accidents in comparison with other diseases will rise from ninth to third rank between 1990 and 2020. Road accidents as cause to death and disability could rank below heart disease and clinical depression, and ahead of stroke and all infectious diseases. Significant reduction to accident rate is achieved in the developing countries by improved road designed maintenance, improved vehicle design, driver education, and law enforcements. However in the developing nations, the rapid growth of personalized vehicles and poor infrastructure, road design, and law enforcement has resulted in growing accident rate.

3.5.2 Air Pollution

All transport modes consume energy and the most common source of energy is from the burning of fossil fuels like coal, petrol, diesel, etc. The relation between air pollution and respiratory disease have been demonstrated by various studies and the detrimental effects on the planet earth is widely recognized recently. The combustion of the fuels releases several contaminants into the atmosphere, including carbon monoxide, hydrocarbons, oxides of nitrogen, and other particulate matter. Hydrocarbons are the result of incomplete combustion of fuels. Particulate matters are minute solid or liquid particles that are suspended in the atmosphere. They include aerosols, smoke, and dust particles. These air pollutants once emitted into the atmosphere , undergo mixing and disperse into the surroundings.

3.5.3 Noise pollution

Sound is acoustical energy released into atmosphere by vibrating or moving bodies where as noise is unwanted sound produced. Transportation is a major contributor of noise pollution, especially in urban areas. Noise is generated during both construction and operation. During construction, operation of large equipments causes considerable noise to the neighborhood. During the operation, noise is generated by the engine and exhaust systems of vehicle, aerodynamic friction, and the interaction between the vehicle and the support system (road-tire, rail-wheel). Extended exposure to excessive sound has been shown to produce physical and psychological damage. Further, because of its annoyance and disturbance, noise adds to mental stress and fatigue.

3.5.4 Energy consumption

The spectacular growth in industrial and economic growth during the past century have been closely related to an abundant supply of inexpensive energy from fossil fuels. Transportation sector is unbelieved to consume more than half of the petroleum products. The compact of the shortage of fuel was experienced during major wars when strict rationing was imposed in many countries. The impact of this had cascading effects on many factors of society, especially in the price escalation of essential commodities. However, this has few positive impacts; a shift to public transport system, a search for energy efficient engines, and alternate fuels. During the time of fuel shortage, people shifted to cheaper public transport system. Policy makers and planners, thereafter gave much emphasis to the public transit which consume less energy per person. The second impact was in the development of fuel-efficient engines and devices and operational and maintenance practices. A fast depleting fossil fuel has accelerated the search for energy efficient and environment friendly alternate energy source. The research is active in the development of bio-fuels, hydrogen fuels and solar energy.

3.5.5 Other impacts

Transportation directly or indirectly affects many other areas of society and few of then are listed below:

Almost all cities uses 20-30 percent of its land in transport facilities. Increased travel requirement also require additional land for transport facilities. A good transportation system takes considerable amount of landform the society. Aesthetics of a region is also affected by transportation. Road networks in quite country side are visual intrusion. Similarly, the transportation facilities like fly-over's are again visual intrusion in urban context. The social life and social pattern of a community is severely affected after the introduction of some transportation facilities. Construction of new transportation facilities often requires substantial relocation of residents and employment opportunities.

Chapter 4

Factors affecting transportation

4.1 Overview

The success of transportation engineering depends upon the co-ordination between the three primary elements, namely the vehicles, the roadways, and the road users. Their characteristics affect the performance of the transportation system and the transportation engineer should have fairly good understanding about them. This chapter elaborated salient human, vehicle, and road factors affecting transportation.

4.2 Human factors affecting transportation

Road users can be defined as drivers, passengers, pedestrians etc. who use the streets and highways. Together,they form the most complex element of the traffic system - the human element - which differentiates Transportation Engineering from all other engineering fields. It is said to be the most complex factor as the human performances varies from individual to individual. Thus, the transportation engineer should deal with a variety of road user characteristics. For example, a traffic signal timed to permit an average pedestrian to cross the street safely may cause a severe hazard to an elderly person. Thus, the design considerations should safely and efficiently accommodate the elderly persons, the children, the handicapped, the slow and speedy, and the good and bad drivers.

4.2.1 Variability

The most complex problem while dealing human characteristics is its variability. The human characteristics like ability to react to a situation, vision and hearing, and other physical and psychological factors vary from person to person and depends on age, fatigue, nature of stimuli, presence of drugs/alcohol etc. The influence of all these factors and the corresponding variability cannot be accounted when a facility is designed. So a standardized value is often used as the design value. The 85th percentile value of different characteristics is taken as a standard. It represents a characteristic that 85 per percent of the population can meet or exceed. For example. if we say that the 85th percentile value of walking speed is about 2 m/s, it means that 85 per cent of people has walking speed faster than 2 m/s. The variability is thus fixed by selecting proper 85th percentile values of the characteristics.

4.2.2 Critical characteristics

The road user characteristics can be of two main types, some of them are quantifiable like reaction time, visualacuity etc. while some others are less quantifiable like the psychological factors, physical strength, fatigue, and dexterity.

4.2.3 Reaction time

The road user is subjected to a series of stimuli both expected and unexpected. The time taken to perform an action according to the stimulus involves a series of stages like:

• Perception: Perception is the process of perceiving the sensations received through the sense organs, nerves and brains. It is actually the recognitions that a stimulus on which a reaction is to happen exists.
• Intellection: Intellection involves the identification and understanding of stimuli.
• Emotion: This stage involves the judgment of the appropriate response to be made on the stimuli like to stop, pass, move laterally etc.
• Volition: Volition is the execution of the decision which is the result of a physical actions of the driver. For example., if a driver approaches an intersection where the signal is red, the driver first sees the signal (perception), he recognizes that is is a red/STOP signal, he decides to stop and finally applies the brake(volition). This sequence is called the PIEV time or perception-reaction time. But apart from the above time, the vehicle itself traveling at initial speed would require some more time to stop. That is, the vehicle traveling with initial speed u will travel for a distance, d = vt where, t is the above said PIEV time. Again, the vehicle would travel some distance after the brake is applied.

4.2.4 Visual acuity and driving

The perception-reaction time depends greatly on the effectiveness of drivers vision in perceiving the objects and traffic control measures. The PIEV time will be decreased if the vision is clear and accurate. Visual acuity relates to the field of clearest vision. The most acute vision is within a cone of 3 to 5 degrees, fairly clear vision within 10 to 12 degrees and the peripheral vision will be within 120 to 180 degrees. This is important when traffic signs and signals are placed, but other factors like dynamic visual acuity, depth perception etc. should also be considered for accurate design. Glare vision and color vision are also equally important. Glare vision is greatly affected by age. Glare recovery time is the time required to recover from the effect of glare after the light source is passed, and will be higher for elderly persons. Color vision is important as it can come into picture in case of sign and signal recognition.

4.2.5 Walking

Transportation planning and design will not be complete if the discussion is limited to drivers and vehicular passengers. The most prevalent of the road users are the pedestrians. Pedestrian traffic along footpaths, sidewalks, crosswalks, safety zones, islands, and over and under passes should be considered. On an average, the pedestrian walking speed can be taken between 1.5 m/sec to 2 m/sec. But the influence of physical, mental, and emotional factors need to be considered. Parking spaces and facilities like signals, bus stops, and over and under passes are to be located and designed according to the maximum distance to which a user will be willingto walk. It was seen that in small towns 90 per cent park within 185 m of their destinations while only 66 per cent park so close in large city.

4.2.6 Other Characteristics

Hearing is required for detecting sounds, but lack of hearing acuity can be compensated by usage of hearing aids. Lot of experiments were carried out to test the drive vigilance which is the ability of a drive to discern environmental signs over a prolonged period. The results showed that the drivers who did not undergo any type

of fatiguing conditions performed significantly better than those who were subjected to fatiguing conditions. But the mental fatigue is more dangerous than skill fatigue. The variability of attitude of drivers with respect to age, sex, knowledge and skill in driving etc. are also important.
Two of the important constituents of transportation system are drivers and users/passengers. Understanding of certain human characteristics like perception - reaction time and visual acuity and their variability are to be considered by Traffic Engineer. Because of the variability in characteristics, the 85Th percentile values of the human characteristics are fixed as standards for design of traffic facilities.

4.3 Vehicle factors

It is important to know about the vehicle characteristics because we can design road for any vehicle but not for an indefinite one. The road should be such that it should cater to the needs of existing and anticipated vehicles. Some of the vehicle factors that affect transportation is discussed below.

4.3.1 Design vehicles

Highway systems accommodate a wide variety of sizes and types of vehicles, from smallest compact passenger cars to the largest double and triple tractor-trailer combinations. According to the different geometric features of highways like the lane width, lane widening on curves, minimum curb and corner radius, clearance heights etc some standard physical dimensions for the vehicles has been recommended. Road authorities are forced to impose limits on vehicular characteristics mainly:

- To provide practical limits for road designers to work to,
- To see that the road space and geometry is available to normal vehicles,
- To implement traffic control effectively and efficiently,
- take care of other road users also.

Taking the above points into consideration, in general, the vehicles can be grouped into motorized two wheeler's, motorized three wheeler's, passenger car, bus, single axle trucks, multi axle trucks, truck trailer combinations, and slow non motorized vehicles.

4.3.2 Vehicle dimensions

The vehicular dimensions which can affect the road and traffic design are mainly: width, height, length, rear overhang, and ground clearance. The width of vehicle affects the width of lanes, shoulders and parking facility. The capacity of the road will also decrease if the width exceeds the design values. The height of the vehicle affects the clearance height of structures like over-bridges, under-bridges and electric and other service lines and also placing of signs and signals. Another important factor is the length of the vehicle which affects the extra width of pavement, minimum turning radius, safe overtaking distance, capacity and the parking facility. The rear overhang control is mainly important when the vehicle takes a right/left turn from a stationary point. The ground clearance of vehicle comes into picture while designing ramps and property access and as bottoming out on a crest can stop a vehicle from moving under its own pulling power.

4.3.3 Weight, axle configuration etc.

The weight of the vehicle is a major consideration during the design of pavements both flexible and rigid. The weight of the vehicle is transferred to the pavement through the axles and so the design parameters are fixed on the basis of the number of axles. The power to weight ratio is a measure of the ease with which a vehicle can move. It determines the operating efficiency of vehicles on the road. The ratio is more important for heavy vehicles. The power to weight ratio is the major criteria which determines the length to which a positive gradient can be permitted taking into consideration the case of heavy vehicles.

4.3.4 Turning radius and turning path

The minimum turning radius is dependent on the design and class of the vehicle. The effective width of the vehicle is increased on a turning. This is also important at an intersection, roundabout, terminals, and parking areas.

4.3.5 Visibility

The visibility of the driver is influenced by the vehicular dimensions. As far as forward visibility is concerned, the dimension of the vehicle and the slope and curvature of wind screens, windscreen wipers, door pillars, etc should be such that:

- Visibility is clear even in bad weather conditions like fog, ice, and rain;
- It should not mask the pedestrians, cyclists or other vehicles;
- During intersection maneuvers.

Equally important is the side and rear visibility when maneuvering especially at intersections when the driver adjusts his speed in order to merge or cross a traffic stream. Rear vision efficiency can be achieved by properly positioning the internal or external mirrors.

4.4 Acceleration characteristics

The acceleration capacity of vehicle is dependent on its mass, the resistance to motion and available power. In general, the acceleration rates are highest at low speeds, decreases as speed increases. Heavier vehicles have lower rates of acceleration than passenger cars. The difference in acceleration rates becomes significant in mixed traffic streams. For example, heavy vehicles like trucks will delay all passengers at an intersection. Again, the gaps formed can be occupied by other smaller vehicles only if they are given the opportunity to pass. The presence of upgrades make the problem more severe. Trucks are forced to decelerate on grades because their power is not sufficient to maintain their desired speed. As trucks slow down on grades, long gaps will be formed in the traffic stream which cannot be efficiently filled by normal passing maneuvers.

4.5 Braking performance

As far as highway safety is concerned, the braking performance and deceleration characteristics of vehicles are of prime importance. The time and distance taken to stop the vehicle is very important as far as the design of various traffic facilities are concerned. The factors on which the braking distance depend are the type of the road and its condition, the type and condition of tire and type of the braking system.

The main characteristics of a traffic system influenced by braking and deceleration performance are:

• Safe stopping sight distance: The minimum stopping sight distance includes both the reaction time and the distance covered in stopping. Thus, the driver should see the obstruction in time to react to the situation and stop the vehicle.

• Clearance and change interval: The Clearance and change intervals are again related to safe stopping distance. All vehicles at a distance further away than one stopping sight distance from the signal when the Yellow is flashed is assumed to be able to stop safely. Such a vehicle which is at a distance equal or greater than the stopping sight distance will have to travel a distance equal to the stopping sight distance plus the width of the street, plus the length of the vehicle. Thus the yellow and all red times should be calculated to accommodate the safe clearance of those vehicles.

• Sign placement: The placement of signs again depends upon the stopping sight distance and reaction time of drivers. The driver should see the sign board from a distance at least equal to or greater than the stopping sight distance. From the examples discussed above, it is clear that the braking and reaction distance computations are very important as far as a transportation system is concerned. Stopping sight distance is a product of the characteristics of the driver, the vehicle and the roadway. and so this can vary with drivers and vehicles. Here the concept of design vehicles gains importance as they assist in general design of traffic facilities thereby enhancing the safety and performance of roadways.

4.6 Road factors

4.6.1 Road surface

The type of pavement is determined by the volume and composition of traffic, the availability of materials, and available funds. Some of the factors relating to road surface like road roughness, tire wear, tractive resistance, noise, light reflection, electrostatic properties etc. should be given special attention in the design, construction and maintenance of highways for their safe and economical operation. Unfortunately, it is impossible to build road surface which will provide the best possible performance for all these conditions. For heavy traffic volumes,a smooth riding surface with good all-weather anti skid properties is desirable. The surface should be chosen to retain these qualities so that maintenance cost and interference to traffic operations are kept to a minimum.

4.6.2 Lighting

Illumination is used to illuminate the physical features of the road way and to aid in the driving task. A luminaire is a complete lighting device that distributes light into patterns much as a garden hose nozzle distributes water. Proper distribution of the light flux from luminaires is one of the essential factors in efficient roadway lighting. It is important that roadway lighting be planned on the basis of many traffic information such as night vehicular traffic, pedestrian volumes and accident experience.

4.6.3 Roughness

This is one of the main factors that an engineer should give importance during the design, construction, and maintenance of a highway system. Drivers tend to seek smoother surface when given a choice. On four-lane highways where the texture of the surface of the inner-lane is rougher than that of the outside lane, passing vehicles tend to return to the outside lane after execution of the passing maneuver. Shoulders or even speed- change lanes may be deliberately roughened as a means of delineation.

4.6.4 Pavement colors

When the pavements are light colored(for example, cement concrete pavements) there is better visibility during day time whereas during night dark colored pavements like bituminous pavements provide more visibility. Contrasting pavements may be used to indicate preferential use of traffic lanes. A driver tends to follow the same pavement color having driven some distance on a light or dark surface, he expects to remain on a surface of that same color until he arrives a major junction point.

4.6.5 Night visibility

Since most accidents occur at night because of reduced visibility, the traffic designer must strive to improve nighttime visibility in every way he can. An important factor is the amount of light which is reflected by the road surface to the drivers' eyes. Glare caused by the reflection of oncoming vehicles is negligible on a dry pavement but is an important factor when the pavement is wet.

4.6.6 Geometric aspects

The roadway elements such as pavement slope, gradient, right of way etc affect transportation in various ways. Central portion of the pavement is slightly raised and is sloped to either sides so as to prevent the ponding of water on the road surface. This will deteriorate the riding quality since the pavement will be subjected to many failures like potholes etc. Minimum lane width should be provided to reduce the chances of accidents. Also the speed of the vehicles will be reduced and time consumed to reach the destination will also be more. Right of way width should be properly provided. If the right of way width becomes less, future expansion will become difficult and the development of that area will be adversely affected. One important other road element is the gradient. It reduces the tractive effort of large vehicles. Again the fuel consumption of the vehicles climbing a gradient is more. The other road element that cannot be avoided are curves. Near curves, chances of accidents are more. Speed of the vehicles is also affected.

Chapter 5

Cross sectional elements

5.1 Overview

The features of the cross-section of the pavement influences the life of the pavement as well as the riding comfort and safety. Of these, pavement surface characteristics affect both of these. Camber, kerbs, and geometry of various cross-sectional elements are important aspects to be considered in this regard. They are explained briefly in this chapter.

5.2 Pavement surface characteristics

For safe and comfortable driving four aspects of the pavement surface are important; the friction between the wheels and the pavement surface, smoothness of the road surface, the light reflection characteristics of the top of pavement surface, and drainage to water.

5.2.1 Friction

Friction between the wheel and the pavement surface is a crucial factor in the design of horizontal curves and thus the safe operating speed. Further, it also affect the acceleration and deceleration ability of vehicles. Lack of adequate friction can cause skidding or slipping of vehicles.

• Skidding happens when the path traveled along the road surface is more than the circumferential movement of the wheels due to friction

• Slip occurs when the wheel revolves more than the corresponding longitudinal movement along the road.Various factors that affect friction are:

• Type of the pavement (like bituminous, concrete, or gravel),

• Condition of the pavement (dry or wet, hot or cold, etc),

• Condition of the tyre (new or old), and

• Speed and load of the vehicle.

The frictional force that develops between the wheel and the pavement is the load acting multiplied by a factor called the coefficient of friction and denoted as f. The choice of the value of f is a very complicated issue since it depends on many variables. IRC suggests the coefficient of longitudinal friction as 0.35-0.4 depending on the speed and coefficient of lateral friction as 0.15. The former is useful in sight distance calculation and the latter in horizontal curve design.

5.2.2 Unevenness

It is always desirable to have an even surface, but it is seldom possible to have such a one. Even if a road is constructed with high quality pavers, it is possible to develop unevenness due to pavement failures. Unevenness affect the vehicle operating cost, speed, riding comfort, safety, fuel consumption and wear and tear of tyres. Unevenness index is a measure of unevenness which is the cumulative measure of vertical undulations of the pavement surface recorded per unit horizontal length of the road. An unevenness index value less than 1500 mm/km is considered as good, a value less than 2500 mm.km is satisfactory up to speed of 100 kmph and values greater than 3200 mm/km is considered as uncomfortable even for 55 kmph.

5.2.3 Light reflection

• White roads have good visibility at night, but caused glare during day time.

• Black roads has no glare during day, but has poor visibility at night

• Concrete roads has better visibility and less glare

It is necessary that the road surface should be visible at night and reflection of light is the factor that answers
it.

5.2.4 Drainage

The pavement surface should be absolutely impermeable to prevent seepage of water into the pavement layers.

Further, both the geometry and texture of pavement surface should help in draining out the water from the surface in less time.

5.3 Camber

Camber or cant is the cross slope provided to raise middle of the road surface in the transverse direction to drain off rain water from road surface. The objectives of providing camber are:

- Surface protection especially for gravel and bituminous roads
- Sub-grade protection by proper drainage
- Quick drying of pavement which in turn increases safety

Too steep slope is undesirable for it will erode the surface. Camber is measured in 1 in n or n% (Eg. 1 in 50 or2%) and the value depends on the type of pavement surface. The values suggested by IRC for various categories of pavement. The common types of camber are parabolic, straight, or combination of them

5.4 Width of carriage way

Width of the carriage way or the width of the pavement depends on the width of the traffic lane and numberof lanes. Width of a traffic lane depends on the width of the vehicle and the clearance. Side clearance improves operating speed and safety. The maximum permissible width of a vehicle is 2.44 and the desirable side clearance for single lane traffic is 0.68 m. This require minimum of lane width of 3.75 m for a single lane road. However, the side clearance required is about 0.53 m, on either side and 1.06 m in the center. Therefore, a two lane road require minimum of 3.5 meter for each lane (Figure 12:2b). The desirable carriage way width recommended by IRC is given in Table 12:2

5.5 Kerbs

Kerbs indicate the boundary between the carriage way and the shoulder or islands or footpaths. Different types of kerbs are

- Low or mountable kerbs : This type of kerbs are provided such that they encourage the traffic to remain in the through traffic lanes and also allow the driver to enter the shoulder area with little difficulty. The height of this kerb is about 10 cm above the pavement edge with a slope which allows the vehicle to climb easily. This is usually provided at medians and channelization schemes and also helps in longitudinal drainage.
- Semi-barrier type kerbs : When the pedestrian traffic is high, these kerbs are provided. Their height is 15 cm above the pavement edge. This type of kerb prevents encroachment of parking vehicles, but at acute emergency it is possible to drive over this kerb with some difficulty.
- Barrier type kerbs : They are designed to discourage vehicles from leaving the pavement. They are provided when there is considerable amount of pedestrian traffic. They are placed at a height of 20 cm above the pavement edge with a steep batter.

• Submerged kerbs : They are used in rural roads. The kerbs are provided at pavement edges between the pavement edge and shoulders. They provide lateral confinement and stability to the pavement.

5.6 Road margins

The portion of the road beyond the carriageway and on the roadway can be generally called road margin. Various elements that form the road margins are given below.

5.6.1 Shoulders

Shoulders are provided along the road edge and are intended for accommodation of stopped vehicles, serve as an emergency lane for vehicles and provide lateral support for base and surface courses. The shoulder should be strong enough to bear the weight of a fully loaded truck even in wet conditions. The shoulder width should be adequate for giving working space around a stopped vehicle. It is desirable to have a width of 4.6 m for the shoulders. A minimum width of 2.5 m is recommended for 2-lane rural highways in India.

5.6.2 Parking lanes

Parking lanes are provided in urban lanes for side parking. Parallel parking is preferred because it is safe for the vehicles moving on the road. The parking lane should have a minimum of 3.0 m width in the case of parallel parking.

5.6.3 Bus-bays

Bus bays are provided by recessing the kerbs for bus stops. They are provided so that they do not obstruct the movement of vehicles in the carriage way. They should be at least 75 meters away from the intersection so that the traffic near the intersections is not affected by the bus-bay.

5.6.4 Service roads

Service roads or frontage roads give access to access controlled highways like freeways and expressways. They run parallel to the highway and will be usually isolated by a separator and access to the highway will be provided only at selected points. These roads are provided to avoid congestion in the expressways and also the speed of the traffic in those lanes is not reduced.

5.6.5 Cycle track

Cycle tracks are provided in urban areas when the volume of cycle traffic is high Minimum width of 2 meter is required, which may be increased by 1 meter for every additional track.

5.6.6 Footpath

Footpaths are exclusive right of way to pedestrians, especially in urban areas. They are provided for the safety of the pedestrians when both the pedestrian traffic and vehicular traffic is high. Minimum width is 1.5 meter and may be increased based on the traffic. The footpath should be either as smooth as the pavement or smoother than that to induce the pedestrian to use the footpath.

5.6.7 Guard rails

They are provided at the edge of the shoulder usually when the road is on an embankment. They serve to prevent the vehicles from running off the embankment, especially when the height of the fill exceeds 3 m.Various designs of guard rails are there. Guard stones painted in alternate black and white are usually used. They also give better visibility of curves at night under headlights of vehicles.

5.7 Width of formation

Width of formation or roadway width is the sum of the widths of pavements or carriage way including separators and shoulders. This does not include the extra land in formation/cutting.

Right of way (ROW) or land width is the width of land acquired for the road, along its alignment. It should be adequate to accommodate all the cross-sectional elements of the highway and may reasonably provide for future development. To prevent ribbon development along highways, control lines and building lines may be provided. Control line is a line which represents the nearest limits of future uncontrolled building activity in relation to a road. Building line represents a line on either side of the road, between which and the road no building activity is permitted at all. The right of way width is governed by:

- Width of formation: It depends on the category of the highway and width of roadway and road margins.
- Height of embankment or depth of cutting: It is governed by the topography and the vertical alignment.
- Side slopes of embankment or cutting: It depends on the height of the slope, soil type etc.
- Drainage system and their size which depends on rainfall, topography etc.
- Sight distance considerations: On curves etc. there is restriction to the visibility on the inner side of the curve due to the presence of some obstructions like building structures etc.
- Reserve land for future widening: Some land has to be acquired in advance anticipating future developments like widening of the road. The importance of reserved land is emphasized by the following. Extra width of land is available for the construction of roadside facilities. Land acquisition is not possible later, because the land may be occupied for various other purposes (buildings, business etc.)

Chapter 6
Sight distance

6.1 Overview

The safe and efficient operation of vehicles on the road depends very much on the visibility of the road ahead of the driver. Thus the geometric design of the road should be done such that any obstruction on the road length could be visible to the driver from some distance ahead . This distance is said to be the sight distance.

6.2 Types of sight distance

Sight distance available from a point is the actual distance along the road surface, over which a driver from a specified height above the carriage way has visibility of stationary or moving objects. Three sight distance situations are considered for design:

- Stopping sight distance (SSD) or the absolute minimum sight distance
- Intermediate sight distance (ISD) is defined as twice SSD

• Overtaking sight distance (OSD) for safe overtaking operation
• Head light sight distance is the distance visible to a driver during night driving under the illumination of head lights
• Safe sight distance to enter into an intersection.

The most important consideration in all these is that at all times the driver traveling at the design speed of the highway must have sufficient carriageway distance within his line of vision to allow him to stop his vehicle before colliding with a slowly moving or stationary object appearing suddenly in his own traffic lane. The computation of sight distance depends on:

• **Reaction time of the driver** Reaction time of a driver is the time taken from the instant the object is visible to the driver to the instant when the brakes are applied. The total reaction time may be split up into four components based on PIEV theory. In practice, all these times are usually combined into a total perception-reaction time suitable for design purposes as well as for easy measurement. Many of the studies shows that drivers require about 1.5 to 2 secs under normal conditions. However, taking into consideration the variability of driver characteristics, a higher value is normally used in design. For example, IRC suggests a reaction time of 2.5 secs.
• **Speed of the vehicle** The speed of the vehicle very much affects the sight distance. Higher the speed, more time will be required to stop the vehicle. Hence it is evident that, as the speed increases, sight distance also increases.
• **Efficiency of brakes** The efficiency of the brakes depends upon the age of the vehicle, vehicle characteristics etc. If the brake efficiency is 100%, the vehicle will stop the moment the brakes are applied. But practically, it is not possible to achieve 100% brake efficiency. Therefore the sight distance required will be more when the efficiency of brakes are less. Also for safe geometric design, we assume that the vehicles have only 50% brake efficiency.
• **Frictional resistance** between the tyre and the road The frictional resistance between the tyre and road plays an important role to bring the vehicle to stop. When the frictional resistance is more, the vehicles stop immediately. Thus sight required will be less. No separate provision for brake efficiency is provided while computing the sight distance. This is taken into account along with the factor of longitudinal friction. IRC has specified the value of longitudinal friction in between 0.35 to 0.4.
• **Gradient of the road**. Gradient of the road also affects the sight distance. While climbing up a gradient, the vehicle can stop immediately. Therefore sight distance required is less. While descending a gradient, gravity also comes into action and more time will be required to stop the vehicle. Sight distance required will be more in this case.

6.3 Stopping sight distance

Stopping sight distance (SSD) is the minimum sight distance available on a highway at any spot having sufficient length to enable the driver to stop a vehicle traveling at design speed, safely without collision with any other obstruction. There is a term called safe stopping distance and is one of the important measures in traffic engineering. It is the distance a vehicle travels from the point at which a situation is first perceived to the time the deceleration is complete. Drivers must have adequate time if they are to suddenly respond to a situation. Thus in highway design, sight distance atleast equal to the safe stopping distance should be provided. The stopping sight distance is the sum of lag distance and the braking distance. Lag distance is the distance the vehicle traveled during the reaction time t and is given by vt, where v is the velocity in m/sec2 .

Braking distance is the distance traveled by the vehicle during braking operation. For a level road this is obtained by equating the work done in stopping the vehicle and the kinetic energy of the vehicle. If F is the maximum frictional force developed and the braking distance is l, then work done against friction in stopping the vehicle is Fl = fWl where W is the total weight of the vehicle. Time-space diagram: Illustration of overtaking sight distance The dynamics of the overtaking operation is given in the figure which is a time-space diagram. The x-axis denotes the time and y-axis shows the distance traveled by the vehicles. The trajectory of the slow moving vehicle (B) is shown as a straight line which indicates that it is traveling at a constant speed. A fast moving vehicle (A) is traveling behind the vehicle B. The trajectory of the vehicle is shown initially with a steeper slope. The dotted line indicates the path of the vehicle A if B was absent. The vehicle A slows down to follow the vehicle B as shown in the figure with same slope from t0 to t1. Then it overtakes the vehicle B and occupies the left lane at time t3. The time duration T = t3 − t1 is the actual duration of the overtaking operation. The snapshots of the road at time t0,t1, and t3 are shown on the left side of the figure. From the Figure 13:1, the overtaking sight distance consists of three parts.

- d1 the distance traveled by overtaking vehicle A during the reaction time t = t1 − t0
- d2 the distance traveled by the vehicle during the actual overtaking operation T = t3 − t1
- d3 is the distance traveled by on-coming vehicle C during the overtaking operation (T).

Then the vehicle A starts to accelerate, shifts the lane, overtake and shift back to the original lane. The vehicle A maintains the spacing s before and after overtaking. The spacing s in m is given by: s = 0.7vb + 6 (13.5) Let T be the duration of actual overtaking. The distance traveled by B during the overtaking operation is 2s+vbT. Also, during this time, vehicle A accelerated from initial velocity vb and overtaking is completed while In case the speed of the overtaken vehicle is not given, it can be assumed that it moves 16 kmph slower the the design speed. On divided highways, d3 need not be considered • On divided highways with four or more lanes, IRC suggests that it is not necessary to provide the OSD, but only SSD is sufficient. Overtaking zones Overtaking zones are provided when OSD cannot be provided throughout the length of the highway. These are zones dedicated for overtaking operation, marked with wide roads. The desirable length of overtaking zones is 5 time OSD and the minimum is three times OSD.

6.4 Sight distance at intersections

At intersections where two or more roads meet, visibility should be provided for the drivers approaching the intersection from either sides. They should be able to perceive a hazard and stop the vehicle if required. Stopping sight distance for each road can be computed from the design speed. The sight distance should be provided such that the drivers on either side should be able to see each other. Design of sight distance at intersections may be used on three possible conditions:

- Enabling approaching vehicle to change the speed
- Enabling approaching vehicle to stop
- Enabling stopped vehicle to cross a main road

Chapter 7
Horizontal alignment II

7.1 Overview

This section discusses the design of superelevation and how it is attained. A brief discussion on pavement widening at curves is also given.

7.2 Guidelines on superelevation

While designing the various elements of the road like superelevation, we design it for a particular vehicle called design vehicle which has some standard weight and dimensions. But in the actual case, the road has to cater for mixed traffic. Different vehicles with different dimensions and varying speeds ply on the road. For example, in the case of a heavily loaded truck with high centre of gravity and low speed, superelevation should be less,otherwise chances of toppling are more. Taking into practical considerations of all such situations, IRC has given some guidelines about the maximum and minimum superelevation etc. These are all discussed in detailin the following sections.

7.2.1 Design of super-elevation

For fast moving vehicles, providing higher superelevation without considering coefficient of friction is safe, i.e. centrifugal force is fully counteracted by the weight of the vehicle or super elevation. For slow moving vehicles, providing lower superelevation considering coefficient of friction is safe, i.e.centrifugal force is counteracted by superelevation and coefficient of friction .

7.2.2 Maximum and minimum super-elevation

Depends on (a) slow moving vehicle and (b) heavy loaded trucks with high CG. IRC specifies a maximum super-elevation of 7 percent for plain and rolling terrain, while that of hilly terrain is 10 percent and urban road is 4 percent. The minimum super elevation is 2-4 percent for drainage purpose, especially for large radius of the horizontal curve.

7.2.3 Attainment of super-elevation

1. Elimination of the crown of the cambered section by:

(a) rotating the outer edge about the crown : The outer half of the cross slope is rotated about the crown at a desired rate such that this surface falls on the same plane as the inner half.

(b) shifting the position of the crown: This method is also known as diagonal crown method. Here the position of the crown is progressively shifted outwards, thus increasing the width of the inner half of cross section progressively.

2. Rotation of the pavement cross section to attain full super elevation by: There are two methods of attaining superelevation by rotating the pavement

(a) rotation about the center line : The pavement is rotated such that the inner edge is depressed and the outer edge is raised both by half the total amount of superelevation, i.e., by E/2 with respect tothe centre.
(b) rotation about the inner edge: Here the pavement is rotated raising the outer edge as well as thecentre such that the outer edge is raised by the full amount of superelevation with respect to the inner edge.
15.3 Radius of Horizontal Curve
The radius of the horizontal curve is an important design aspect of the geometric design. The maximum comfortable speed on a horizontal curve depends on the radius of the curve. Although it is possible to design the curve with maximum superelevation and coefficient of friction, it is not desirable because re-alignment would be required if the design speed is increased in future. Therefore, a ruling minimum radius R ruling can be derived by assuming maximum superelevation and coefficient of friction.
Ideally, the radius of the curve should be higher than Rruling. However, very large curves are also not desirable. Setting out large curves in the field becomes difficult. In addition, it also enhances driving strain.

7.4 Extra widening

Extra widening refers to the additional width of carriageway that is required on a curved section of a road over and above that required on a straight alignment. This widening is done due to two reasons: the first and most important is the additional width required for a vehicle taking a horizontal curve and the second is due to the
tendency of the drivers to ply away from the edge of the carriageway as they drive on a curve. The first is referred as the mechanical widening and the second is called the psychological widening. These are discussed in detail below.

7.4.1 Mechanical widening

The reasons for the mechanical widening are: When a vehicle negotiates a horizontal curve, the rear wheels follow a path of shorter radius than the front wheels as shown in figure 15.5. This phenomenon is called off- tracking, and has the effect of increasing the effective width of a road space required by the vehicle. Therefore, to provide the same clearance between vehicles traveling in opposite direction on curved roads as is provided on straight sections, there must be extra width of carriageway available. This is an important factor when high
proportion of vehicles are using the road. Trailor trucks also need extra carriageway, depending on the type of joint. In addition speeds higher than the design speed causes transverse skidding which requires additional width for safety purpose. The expression for extra width can be derived from the simple geometry of a vehicle at a horizontal curve as shown in figure 15.5. Let R1 is the radius of the outer track line of the rear wheel, R2 is the radius of the outer track line of the front wheel l is the distance between the front and rear wheel, n is the number of lanes, then the mechanical widening Wm .