

Chapter 1

Introduction

1.1 Preamble

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. (Introduction to Transportation Engineering 1.1 Tom V. Mathew and K V Krishna Rao).

Transportation engineering or **transport engineering** is the application of technology and scientific principles to the planning, functional design, operation and management of facilities for any mode of transportation in order to provide for the safe, efficient, rapid, comfortable, convenient, economical, and environmentally compatible movement of people and goods (transport). It is a sub-discipline of civil engineering.

Transportation engineering, as practiced by civil engineers, primarily involves planning, design, construction, maintenance, and operation of transportation facilities. The facilities support air, highway, railroad, pipeline, water, and even space transportation. The design aspects of transportation engineering include the sizing of transportation facilities (how many lanes or how much capacity the facility has), determining the materials and thickness used in pavement designing the geometry (vertical and horizontal alignment) of the roadway (or track).

The planning aspects of transportation engineering relate to elements of urban planning, and involve technical forecasting decisions and political factors. Technical forecasting of passenger travel usually involves an urban transportation planning model, requiring the estimation of trip generation (number of purposeful trips), trip distribution (destination

choice, where the traveler is going), mode choice (mode that is being taken), and route assignment (the streets or routes that are being used). More sophisticated forecasting can include other aspects of traveler decisions, including auto ownership, trip chaining (the decision to link individual trips together in a tour) and the choice of residential or business location (known as land use forecasting). Passenger trips are the focus of transportation engineering because they often represent the peak of demand on any transportation system.

Before any planning occurs an engineer must take what is known as an inventory of the area or, if it is appropriate, the previous system in place. This inventory or database must include information on population, land use, economic activity, transportation facilities and services, travel patterns and volumes, laws and ordinances, regional financial resources, and community values and expectations. These inventories help the engineer create business models to complete accurate forecasts of the future conditions of the system. (wikipedia.com)



The engineering of this roundabout in attempts to make traffic flow free-moving. (google.com)

Figure 1.1

1.2 Significance of the study

The main purpose of this study is to understand what Transportation Engineering is about and its role in the development of human civilization.

1.3 Objectives of study

The overall objective of this term paper is to uncover the scope: Transportation Engineering and appreciate its relevance within the civil engineering profession.

1.4 Methods

The approach utilized in this term report follows an array of theoretical work which include:

- Review of available literature as made available on the internet.
- Furthermore, consulting with books in other to obtain depth on the subject.

1.5 Scope of study

- To report comprehensibly what transportation engineering is (as a branch of Civil Engineering)
- To discuss the role of Transportation Engineers in the society.
- Highlight the major branches in Transportation Engineering.

1.6 Arrangement of reports

This report is presented in five chapters:

Chapter 1: presents the introduction to the work with highlights on the background of study, significance of study, objectives, methodology, scope of the study and report format.

Chapter 2: contains a review of relevant technical literature on transportation engineering and its contribution to human civilization.

Chapter 3: Study on Transportation Planning & Geometric Design.

Chapter 4: Study on Pavement Design and Analysis.

Chapter 5: Study on Traffic Engineering, with focus on safety to the public. A brief summary, conclusions and references on the above studies.

Chapter 2

Literature Review

2.1 Overview

The primary reference for this chapter is as follows:

Introduction to Transportation Engineering 1.1 Tom V. Mathew and K V Krishna Rao.

"ITE – The Transportation Profession" (<http://www.ite.org/career/index.asp>).

From the beginning of history, human sensitivity has revealed an urge for mobility leading to a measure of society's progress. The history of this mobility or transport is the history of civilization. For any country to develop with right momentum, modern and efficient transport as an infrastructure is a must. 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.

2.2 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.

2.3 Diverse characteristics

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

- Multi-modal: Covering all modes of transport; air, land, and sea for both passenger and freight.
- Multi-sector: Encompassing the problems and viewpoints of government, private industry, and public.

- 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, regulatory, institutional and financial policies.
- 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.
- Multi-disciplinary: Drawing on the theories and methods of engineering, economics, operations research, political science, psychology, other natural, and social sciences, management and law.

2.3.1 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. But, now new systems like LRT, MRTS, etc. over a variety of alternatives.
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.

2.4 Transportation Engineering

Transportation engineering, as practiced by civil engineers, primarily involves planning, design, construction, maintenance, and operation of transportation facilities. The facilities support air, highway, railroad, pipeline, water, and even space transportation.

The design aspects of transportation engineering include the sizing of transportation facilities (how many lanes or how much capacity the facility has), determining the materials and thickness used in pavement designing the geometry (vertical and horizontal alignment) of the roadway (or track).

2.4.1 The Branches of Transportation Engineering

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

2.4.2 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.

2.4.3 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.

2.4.4 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.

2.4.5 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 flow behavior and characteristics by extensive collection of traffic flow data and analysis. Based on this analysis, traffic flow 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.

2.5 Role of Transportation Engineering

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 systems and their interaction with activity systems; which requires understanding of the basic theoretical concepts and available empirical knowledge.

2.6 Role of Transportation in Society

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.

2.6.1 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.

2.6.2 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.

2.6.3 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.

2.6.4 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.

2.7 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.

2.7.1 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.

2.7.2 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.

2.7.3 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, whereas 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.

2.8 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 units.

2.8.1 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 this information to all the country. However, with the advent of communications, its importance is slightly reduced.

2.8.2 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.

2.9 Environmental role of transportation

The negative effects of transportation are 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.

2.9.1 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. How-ever in the developing nations, the rapid growth of personalized vehicles and poor infrastructure, road design, and law enforcement has resulted in growing accident rate.

2.9.2 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.

2.9.3 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 equipment's 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.

2.9.4 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 unbelievably to consume more than half of the petroleum products. The impact 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.

2.9.5 Factors affecting transportation

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.

2.9.6 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.

2.9.7 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.

2.9.8 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 makes 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.

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 distance to decelerate from one speed to another is given by:

$$d = \frac{v^2 - u^2}{f + g}$$

where d is the braking distance, v and u are the initial and final speed of the vehicle, f is the coefficient of forward rolling and skidding friction and g is the grade in decimals. 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.

2.9.9 Road factors

- ⇒ 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.

- ⇒ 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.

⇒ 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.

⇒ 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.

⇒ 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.

⇒ 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.

Summary

The roles of transportation in society can be classified according to economic, social, political and environmental roles. The social role of transport has caused people to live in permanent settlements and has given chances of sustainable developments. Regarding political role, large areas can now be very easily governed with the help of good transportation system. The environmental effects are usually viewed negatively.

Transportation engineering is a very diverse and multidisciplinary field, which deals with the planning, design, operation and maintenance of transportation systems. Good transportation is that which provides safe, rapid, comfortable, convenient, economical, and environmentally compatible movement of both goods and people. This profession carries a distinct societal responsibility. Transportation planners and engineers recognize the fact that transportation systems constitute a potent force in shaping the course of regional development. Planning and development of transportation facilities generally raises living standards and enhances the aggregate of community values.

Chapter 3

Transportation Planning & Geometric Design

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.

3.1.1 Why are highways so important?

Highways are vitally important to a country's economic development. The construction of a high quality road network directly increases a nation's economic output by reducing journey times and costs, making a region more attractive economically. The actual construction process will have the added effect of stimulating the construction market.

3.2 Highway planning

The process of transportation planning entails developing a transportation plan for an urban region. It is an ongoing process that seeks to address the transport needs of the inhabitants of the area, and with the aid of a process of consultation with all relevant groups, strives to identify and implement an appropriate plan to meet these needs.

Transportation planning has become institutionalized; federal guidelines, regulations, and requirements for local planning are often driving forces behind existing planning methods.

Among the factors that may justify a transportation project are improvements in traffic flow and safety, energy consumption, travel time, economic growth, and accessibility. Usually, cost is a major factor, and so the process will include estimates of the construction, maintenance, and operating costs.

The process must be flexible enough to be applicable to any transportation project or system, because the kinds of problems that transportation engineers work on will vary over time. Transportation has undergone considerable change in emphasis over a 200-

year period; such modes as canals, railroads, highways, air, and public transit have each been dominant at one time or another. Thus, the activities of transportation engineers have varied considerably during this period, depending on society's needs and concerns. Examples of changing societal concerns include energy conservation, traffic congestion, environmental impacts, safety, security, efficiency, productivity, and community preservation. The transportation planning process is not intended to furnish a decision or to give a single result that must be followed, although it can do so in relatively simple situations.

Rather, the process is intended to provide the appropriate information to those who will be affected and those responsible for deciding whether the transportation project should go forward.

3.3 Basic Elements of Transportation Planning

The transportation planning process comprises seven basic elements, which are interrelated and not necessarily carried out sequentially. The information acquired in one phase of the process may be helpful in some earlier or later phase, so there is a continuity of effort that should eventually result in a decision. The elements in the process are:

- Situation definition
- Problem definition
- Search for solutions
- Analysis of performance
- Evaluation of alternatives
- Choice of project
- Specification and construction

3.3.1 Situation Definition

The first step in the planning process is situation definition, which involves all of the activities required to understand the situation that gave rise to the perceived need for a transportation improvement. In this phase, the basic factors that created the present situation are described, and the scope of the system to be studied is delineated. The present system is analyzed and its characteristics are described. Information about the surrounding area, its people, and their travel habits may be obtained.

3.3.2 Problem Definition

The purpose of this step is to describe the problem in terms of the objectives to be accomplished by the project and to translate those objectives into criteria that can be quantified. Objectives are statements of purpose, such as to reduce traffic congestion; to improve safety; to maximize net highway-user benefits; and to reduce noise. Criteria are the measures of effectiveness that can be used to quantify the extent to which a proposed transportation project will achieve the stated objectives. For example, the objective "to reduce traffic congestion" might use "travel time" as the measure of effectiveness. The characteristics of an acceptable system should be identified, and specific limitations and requirements should be noted. Also, any pertinent standards and restrictions that the proposed transportation project must conform to should be understood.

3.3.3 Search for Solutions

In this phase of the planning process, consideration is given to a variety of ideas, designs, locations, and system configurations that might provide solutions to the problem. This is the brainstorming stage, in which many options may be proposed for later testing and evaluation. Alternatives can be proposed by any group or organization.

In fact, the planning study may have been originated to determine the feasibility of a particular project or idea, such as adding bike lanes to reduce traffic volumes. The transportation engineer has a variety of options available in any particular situation, and any or all may be considered in this idea-generating phase. Among the options that might

be used are different types of transportation technology or vehicles, various system or network arrangements, and different methods of operation. This phase also includes preliminary feasibility studies, which might narrow the range of choices to those that appear most promising. Some data gathering, field testing, and cost estimating may be necessary at this stage to determine the practicality and financial feasibility of the alternatives being proposed.

3.3.4 Analysis of Performance

The purpose of performance analysis is to estimate how each of the proposed alternatives would perform under present and future conditions. The criteria identified in the previous steps are calculated for each transportation option. Included in this step is a determination of the investment cost of building the transportation project, as well as annual costs for maintenance and operation. This element also involves the use of mathematical models for estimating travel demand. The number of persons or vehicles that will use the system is determined, and these results, expressed in vehicles or persons/hour, serve as the basis for project design. Other information about the use of the system (such as trip length, travel by time of day, and vehicle occupancy) are also determined and used in calculating user benefits for various criteria or measures of effectiveness.

Environmental effects of the transportation project (such as noise and air pollution levels and acres of land required) are estimated. These non-user impacts are calculated in situations where the transportation project could have significant impacts on the community or as required by law.

This task is sometimes referred to as the transportation planning process, but it is really a systems analysis process that integrates system supply on a network with travel demand forecasts to show equilibrium travel flows.

3.3.5 Evaluation of Alternatives

The purpose of the evaluation phase is to determine how well each alternative will achieve the objectives of the project as defined by the criteria. The performance data produced in the analysis phase are used to compute the benefits and costs that will result if the project is selected. In cases where the results cannot be reduced to a single monetary value, a weighted ranking for each alternative might be produced and compared with other proposed projects. Other economic tests might also be applied, including the net present worth of benefits and costs.

3.3.6 Choice of Project

Project selection is made after considering all the factors involved. In a simple situation, for example, where the project has been authorized and is in the design phase, a single criterion (such as cost) might be used and the chosen project would be the one with the lowest cost. With a more complex project, however, many factors have to be considered, and selection is based on how the results are perceived by those involved in decision-making. If the project involves the community, it may be necessary to hold additional public hearings. A bond issue or referendum may be required.

It is possible that none of the alternatives will meet the criteria or standards, and additional investigations will be necessary. The transportation engineer, who participates in the planning process, may have developed a strong opinion as to which alternative to select. Such bias could result in the early elimination of promising alternatives or the presentation to decision-makers of inferior projects. If the engineer is acting professionally and ethically, he or she will perform the task such that the appropriate information is provided to make an informed choice and that every feasible alternative has been considered. Before deciding whether or not to build the proposed bridge, decision-makers look carefully at the revenue-cost forecasts and would likely consider projects that appear to be financially sound. The site location is selected based on a careful study of the factors involved. The information gathered in the earlier phases would

be used, together with engineering judgment and political considerations, to arrive at a final project selection.

3.3.7 Specification and Construction

Once the transportation project has been selected, the project moves into a detailed design phase in which each of the components of the facility is specified. For a transportation facility, this involves its physical location, geometric dimensions, and structural configuration. Design plans are produced that can be used by contractors to estimate the cost of building the project. When a construction firm is selected, these plans will be the basis on which the project will be built.

For the bridge project, once a decision to proceed has been made, a design is produced that includes the type of superstructure, piers and foundations, roadway widths and approach treatment, as well as appurtenances such as tollbooths, traffic signals, and lighting. These plans are made available to contractors, who submit bids for the construction of the bridge. If a bid does not exceed the amount of funds available and the contractor is deemed qualified to do the work, the project proceeds to the construction phase. Upon completion, the new bridge is turned over to the local transportation authority for operation and maintenance.

3.3.8 Transportation Planning Organization

In carrying out the urban transportation planning process, several committees represent various community interests and viewpoints. These committees are the policy committee, the technical committee, and the citizens' advisory committee. They also interact with permanent planning entities, such as the regional metropolitan planning organization (MPO).

Policy Committee

The policy committee is composed of elected or appointed officials, such as the mayor and director of public works, who represent the governing bodies or agencies that will

be affected by the results. This committee makes the basic policy decisions and acts as a board of directors for the study. They will decide on management aspects of the study as well as key issues of a financial or political nature.

Technical Committee

The technical committee is composed of the engineering and planning staffs that are responsible for carrying out the work or evaluating the technical aspects of the project prepared by consultants. This group will assure that the necessary evaluations and cost comparisons for each project alternative are complete and will supervise the technical details of the entire process. Typically, the technical committee will include highway, transit, and traffic engineers, as well as other specialists in land-use planning, economics, and computer modeling.

Citizens' Advisory Committee

The citizens' advisory committee is composed of a cross-section of the community and may include representatives from labor, business, interested citizens, and members of community interest groups. The committee's function is to express community goals and objectives, to suggest alternatives, and to react to proposed alternatives. Through this committee structure, an open dialogue is facilitated between the policy makers, technical staff, and the community. When a selection is made and recommendations are produced by the study, they should be based on consensus of all interested parties. Although agreement is not always achieved, the citizens' advisory committee serves as a means to increase communication to assure that the final plan which results from the process reflects community interests.

Metropolitan Planning Organization (MPO)

A metropolitan planning organization (MPO) is a transportation policy-making organization made up of representatives from local government and transportation authorities. For example, an MPO representing a city and a county might have a policy

board with five voting members: two from the city council, two from the county Board of Supervisors, and one from the state highway department. The MPO policy board

3.3.9 Implementation of Transportation Planning Recommendations

There is no single model that represents how each state or region implements projects recommended as a result of the transportation planning process, as implementation is governed by state laws and processes (in addition to federal requirements). Figure 3.0 illustrates how recommendations from the planning process might be implemented in a typical state. There are four relevant processes:

- The transportation planning process entails the generation of plans for various types of transportation facilities and programs. Such studies may include a 20-year comprehensive plan created by a regional planning body or specific jurisdiction, project-specific studies of a particular corridor or location, and statewide plans. The creation of these plans typically includes some degree of public involvement, such as public hearings, citizen surveys, or meetings with citizen committees. This process is also guided by federal requirements for state and MPO planning processes. For example, the metropolitan area's long-range plan must be financially constrained such that the projects recommended by the plan do not exceed the forecast for revenue that will be available.
- The transportation programming process is the act of reconciling recommended projects from the planning process with the amount of funds available over an expected period of time, usually between two and six years. The transportation program is thus a list of projects and costs that can be supported by the expected revenues.
- The preliminary engineering and right of way process occurs after a project has been selected. Within this process, variations of the alignment may be considered and environmental studies may be conducted, including solicitation of public input through project-specific hearings. The outcome of these environmental studies may result in no change to the project, a decision to implement mitigation measures such as the creation of wetlands to compensate for wetlands destroyed, a modification to the project such as a new alignment, or a termination of the project.

- The construction process entails advertising the project, soliciting bids, and constructing the project.

Figure 3. illustrates the complexity of the relationship between the transportation planning process and these other project development processes. Clearly, stakeholder involvement does not stop with the completion of a region's transportation plan, meaning there are a variety of opportunities to change the outcome of the plan's recommendations once they have been approved by the MPO and other governing bodies. This figure also illustrates that the practice of transportation planning is incremental, with changes being made until the construction process is underway. There are also a variety of requirements that require coordination of individual bodies in order for a recommendation to be implemented. For example, Figure 11.6 shows that for projects in the MPO area to receive federal funds, the MPO must include the project in its Transportation Improvement Program (TIP), which is a list of projects that the MPO wishes to be undertaken within the next three years (or more). The TIP must be financially constrained; that is, only projects for which funds are available may be placed in the TIP. The TIP in turn is incorporated into the state transportation improvement program (STIP) which is then submitted by the state to FHWA (or FTA) for approval. Finally, the "decision makers" refer to individuals with specific authority at various points throughout the planning, programming, environmental, and construction processes. Decision makers include elected officials in the legislative branch who establish total funds available for the transportation program, special boards that approve the projects that comprise the transportation program, citizens and advocacy groups who influence the outcome of project and program hearings, local and regional officials who make recommendations from their transportation plans, and federal officials who approve projects.

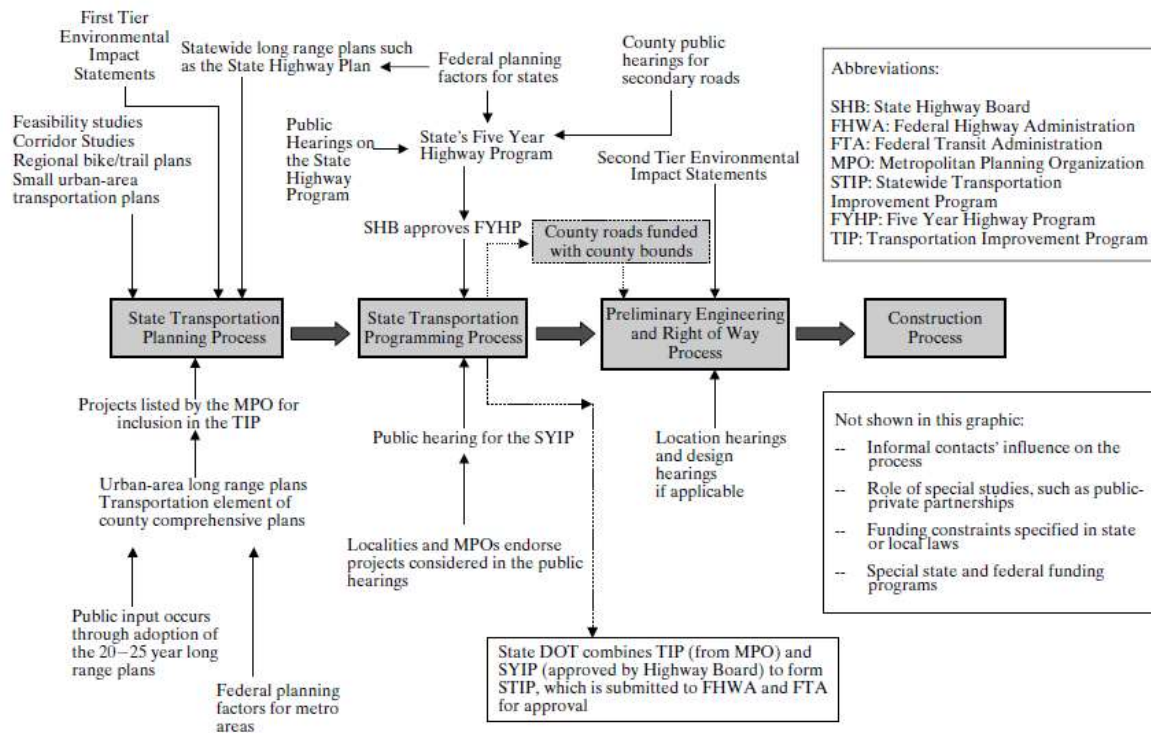


Figure 3.1 Project Development Process

3.4 Urban Transportation Planning

Urban transportation planning involves the evaluation and selection of highway or transit facilities to serve present and future land uses. For example, the construction of a new shopping center, airport, or convention center will require additional transportation services. Also, new residential development, office space, and industrial parks will generate additional traffic, requiring the creation or expansion of roads and transit services. The process must also consider other proposed developments and improvements that will occur within the planning period.

Urban transportation planning is concerned with two separate time horizons. The first is a short-term emphasis intended to select projects that can be implemented within a one-to three-year period. These projects are designed to provide better management of existing facilities by making them as efficient as possible. The second time horizon deals

with the long-range transportation needs of an area and identifies the projects to be constructed over a 20-year period. Short-term projects involve programs such as traffic signal timing to improve flow, car and van pooling to reduce congestion, park-and-ride fringe parking lots to increase transit ridership, and transit improvements.

Long-term projects involve programs such as adding new highway elements, additional bus lines or freeway lanes, rapid transit systems and extensions, or access roads to airports or shopping malls.

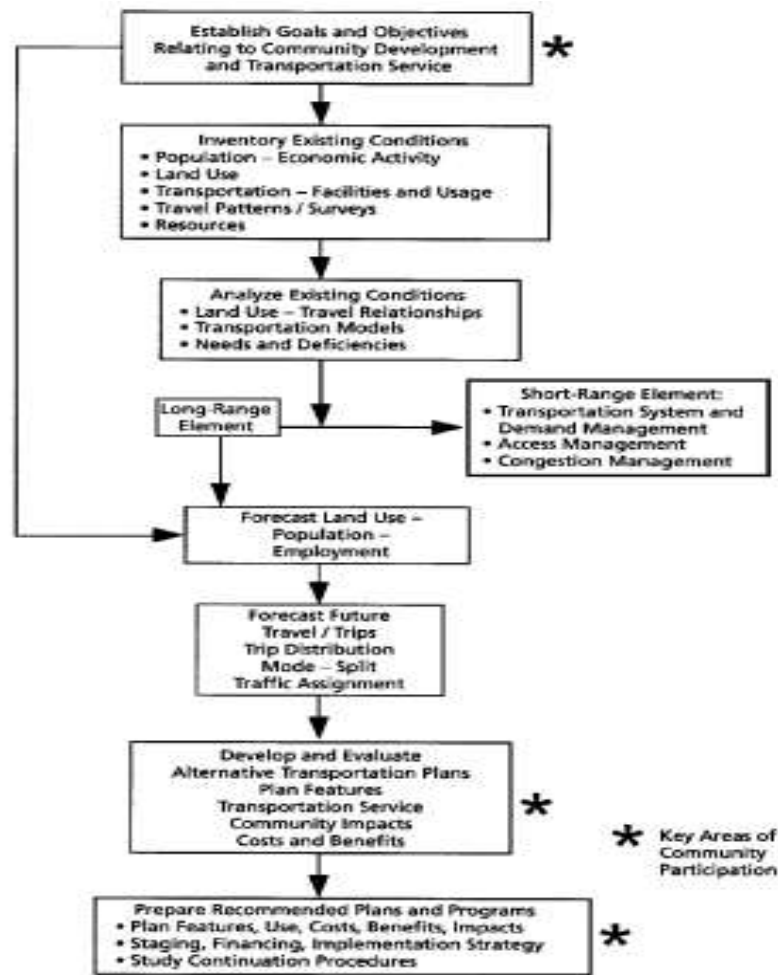


Figure 3.2 Comprehensive Urban Area Transportation Planning Process

3.5 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 fundamental objective of geometric design is to produce a smooth-flowing and safe highway facility, an objective that only can be achieved by providing a consistent design standard that satisfies the characteristics of the driver and the vehicles that use the road. The underlying principles are common to a great extent. Therefore, emphasis will be normally given for the geometric design of roads.

3.5.1 Factors Influencing Highway Design

Highway design is based on specified design standards and controls which depend on the following roadway system factors:

- Functional classification
- Design hourly traffic volume and vehicle mix
- Design speed
- Design vehicle
- Cross section of the highway, such as lanes, shoulders, and medians
- Presence of heavy vehicles on steep grades
- Topography of the area that the highway traverses
- Level of service
- Available funds
- Safety
- Social and environmental factors

These factors are often interrelated. For example, design speed depends on functional classification which is usually related to expected traffic volume. The design speed may also depend on the topography, particularly in cases where limited funds are available. In most instances, the principal factors used to determine the standards to which a

particular highway will be designed are the level of service to be provided, expected traffic volume, design speed, and the design vehicle. These factors, coupled with the basic characteristics of the driver, vehicle, and road, are used to determine standards for the geometric characteristics of the highway, such as cross sections and horizontal and vertical alignments. For example, appropriate geometric standards should be selected to maintain a desired level of service for a known proportional distribution of different types of vehicles.

3.5.1 Highway Functional Classification

Highways are classified according to their functions in terms of the service they provide.

The classification system facilitates a systematic development of highways and the logical assignment of highway responsibilities among different jurisdictions. Highways and streets are categorized as rural or urban roads, depending on the area in which they are located. This initial classification is necessary because urban and rural areas have significantly different characteristics with respect to the type of land use and population density, which in turn influences travel patterns. Within the classification of urban and rural, highways are categorized into the following groups:

- Principal arterials
- Minor arterials
- Major collectors
- Minor collectors
- Local roads and streets

Freeways are not listed as a separate functional class since they are generally classified as part of the principal arterial system. However, they have unique geometric criteria that require special design consideration.

Functional System of Urban Roads

Urban roads comprise highway facilities within urban areas as designated by responsible state and local officials to include communities with a population of at least 5000 people. Some states use other values, for example, the Virginia Department of Transportation uses a population of 3500 to define an urban area. Urban areas are further subdivided into urbanized areas with populations of 50,000 or more and small urban areas with populations between 5000 and 50,000. Urban roads are functionally classified into principal arterials, minor arterials, collectors, and local roads. A schematic of urban functional classification is illustrated in **Figure 3.3** for a suburban environment.

Urban Principal Arterial System: This system of highways serves the major activity centers of the urban area and consists mainly of the highest-traffic-volume corridors.

It carries a high proportion of the total vehicle-miles of travel within the urban area

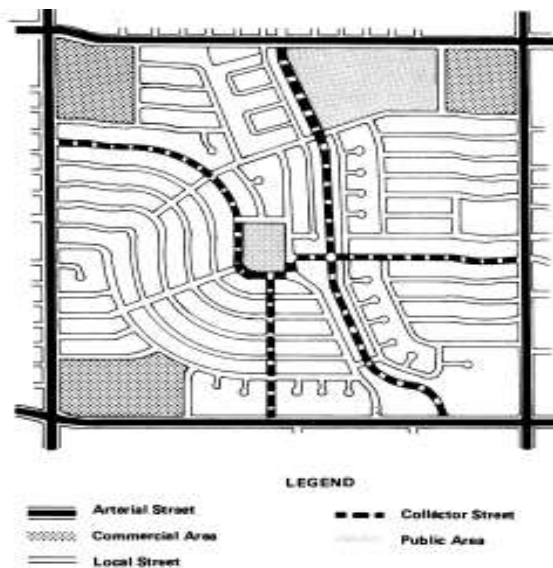


Figure 3.3 Schematic Illustration of the Functional Classes for a Suburban Road Network

including most trips with an origin or destination within the urban area. The system also serves trips that bypass the central business districts (CBDs) of urbanized areas. All controlled-access facilities are within this system, although controlled access is not

necessarily a condition for a highway to be classified as an urban principal arterial. Highways within this system are further divided into three subclasses based mainly on the type of access to the facility: (1) interstate, with fully-controlled access and grade separated interchanges; (2) expressways, which have controlled access but may also include at-grade intersections; and (3) other principal arterials (with partial or no controlled access).

Urban Minor Arterial System: Streets and highways that interconnect with and augment the urban primary arterials are classified as urban minor arterials. This system serves trips of moderate length and places more emphasis on land access than the primary arterial system. All arterials not classified as primary are included in this class. Although highways within this system may serve as local bus routes and may connect communities within the urban areas, they do not normally go through identifiable neighborhoods. The spacing of minor arterial streets in fully developed areas is usually not less than 1 mile, but the spacing can be 2 to 3 miles in suburban fringes.

Urban Collector Street System: The main purpose of streets within this system is to collect traffic from local streets in residential areas or in CBDs and convey it to the arterial system. Thus, collector streets usually go through residential areas and facilitate traffic circulation within residential, commercial, and industrial areas.

Urban Local Street System: This system consists of all other streets within the urban area that are not included in the three systems described earlier. The primary purposes of these streets are to provide access to abutting land and to the collector streets. Through traffic is discouraged on these streets.

Functional System of Rural Roads
Highway facilities outside urban areas comprise the rural road system. These highways are categorized as principal arterials, minor arterials, major collectors, minor collectors, and locals. **Figure 3.4** is a schematic illustration of a functionally classified rural highway network.

Rural Principal Arterial System: This system consists of a network of highways that serves most of the interstate trips and a substantial amount of intrastate trips. Virtually all highway trips between urbanized areas and a high percentage of trips between small urban areas with populations of 25,000 or more are made on this system. The system is further divided into freeways (which are divided highways with fully controlled access and no at-grade intersections) and other principal arterials not classified as freeways.

Rural Minor Arterial System: This system of roads augments the principal arterial system in the formation of a network of roads that connects cities, large towns, and other traffic generators, such as large resorts. Travel speeds on these roads are relatively high with minimum interference to through movement.

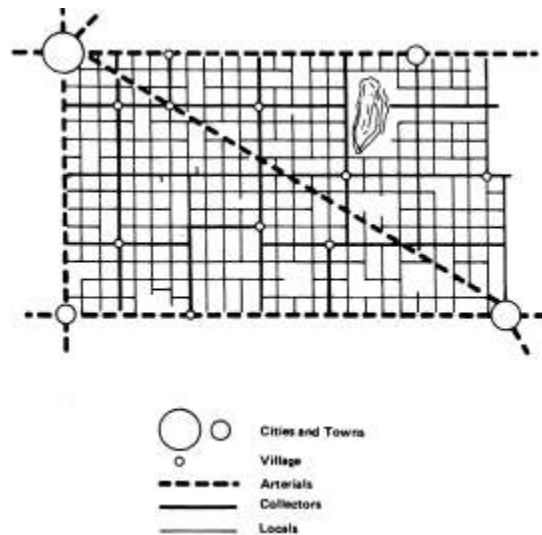


Figure 3.4 Schematic Illustration of a Functionally Classified Rural Highway Network

Rural Collector System: Highways within this system carry traffic primarily within individual counties, and trip distances are usually shorter than those on the arterial roads. This system of roads is subdivided into major collector roads and minor collector roads.

Rural Major Collector System: Routes under this system carry traffic primarily to and from county seats and large cities that are not directly served by the arterial system. The system also carries the main intra county traffic.

Rural Minor Collector System: This system consists of routes that collect traffic from local roads and convey it to other facilities. One important function of minor collector roads is that they provide linkage between rural hinterland and locally important traffic generators such as small communities.

Rural Local Road System: This system consists of all roads within the rural area not classified within the other systems. These roads serve trips of relatively short distances and connect adjacent lands with the collector roads.

3.6 Summary

This chapter presents the fundamental principles of highway geometric design, together with the necessary formulas required for the design of the vertical and horizontal alignments of the highway. The basic characteristics of the driver, pedestrian, vehicle, and road are used to determine the geometric characteristics of any highway or bikeway. The fundamental characteristic on which several design standards are based is the design speed, which depends on the type of facility being considered.

Chapter 4

Pavement Analysis and Design

4.1 Overview

A highway pavement is a structure consisting of superimposed layers of processed materials above the natural soil sub-grade, whose primary function is to distribute the applied vehicle loads to the sub-grade. The pavement structure should be able to provide a surface of acceptable riding quality, adequate skid resistance, favorable light reflecting characteristics, and low noise pollution. The ultimate aim is to ensure that the transmitted stresses due to wheel load are sufficiently reduced, so that they will not exceed bearing capacity of the subgrade.

Two types of pavements are generally recognized as serving this purpose, namely flexible pavements and rigid pavements. This chapter gives an overview of pavement types, layers, and their functions, and pavement failures. Improper design of pavements leads to early failure of pavements affecting the riding quality.

4.2 Requirements of a pavement

An ideal pavement should meet the following requirements:

- Sufficient thickness to distribute the wheel load stresses to a safe value on the sub-grade soil,
- Structurally strong to withstand all types of stresses imposed upon it,
- Adequate coefficient of friction to prevent skidding of vehicles,
- Smooth surface to provide comfort to road users even at high speed,
- Produce least noise from moving vehicles,
- Dust proof surface so that traffic safety is not impaired by reducing visibility,
- Impervious surface, so that sub-grade soil is well protected, and
- Long design life with low maintenance cost.

4.2.1 Types of pavements

The pavements can be classified based on the structural performance into two, flexible pavements and rigid pavements.

In flexible pavements, wheel loads are transferred by grain-to-grain contact of the aggregate through the granular structure. The flexible pavement, having less flexural strength, acts like a flexible sheet (e.g. bituminous road).

On the contrary, in rigid pavements, wheel loads are transferred to sub-grade soil by flexural strength of the pavement and the pavement acts like a rigid plate (e.g. cement concrete roads). In addition to these, composite pavements are also available. A thin layer of flexible pavement over rigid pavement is an ideal pavement with most desirable characteristics. However, such pavements are rarely used in new construction because of high cost and complex analysis required.

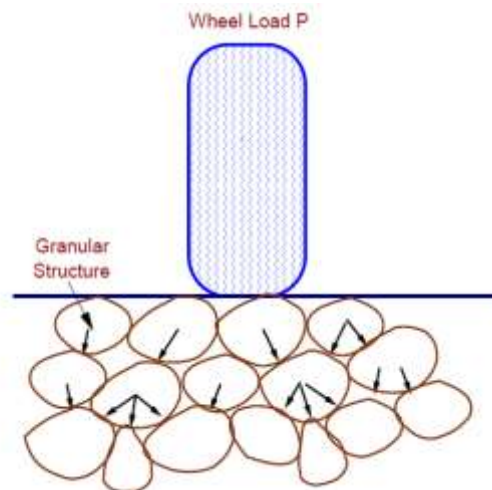


Figure 4:1: Load transfer in granular structure

4.3 Flexible pavements

Flexible pavements will transmit wheel load stresses to the lower layers by grain-to-grain transfer through the points of contact in the granular structure (see Figure 19:1). The

wheel load acting on the pavement will be distributed to a wider area, and the stress decreases with the depth. Taking advantage of this stress distribution characteristic, flexible pavements normally has many layers. Hence, the design of flexible pavement uses the concept of layered system. Based on this, flexible pavement may be constructed in a number of layers and the top layer has to be of best quality to sustain maximum compressive stress, in addition to wear and tear.

The lower layers will experience lesser magnitude of stress and low quality material can be used. Flexible pavements are constructed using bituminous materials. These can be either in the form of surface treatments (such as bituminous surface treatments generally found on low volume roads) or, asphalt concrete surface courses (generally used on high volume roads such as national highways). Flexible pavement layers reflect the deformation of the lower layers on to the surface layer (e.g., if there is any undulation in sub-grade then it will be transferred to the surface layer). In the case of flexible pavement, the design is based on overall performance of flexible pavement, and the stresses produced should be kept well below the allowable stresses of each pavement layer.

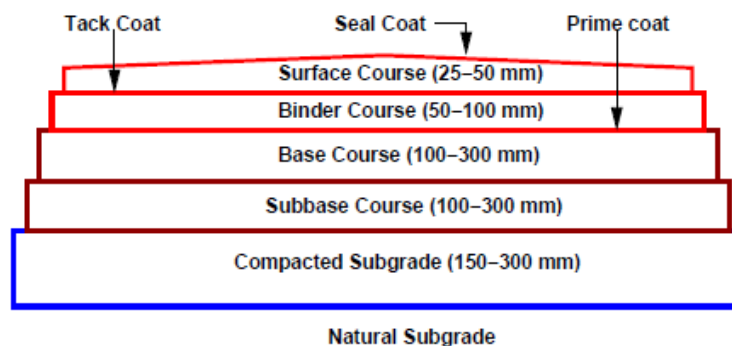


Figure 4:2: Typical cross section of a flexible pavement

4.3.1 Types of Flexible Pavements

The following types of construction have been used in flexible pavement:

- Conventional layered flexible pavement,
- Full - depth asphalt pavement, and
- Contained rock asphalt mat (CRAM).

Conventional flexible pavements are layered systems with high quality expensive materials are placed in the top where stresses are high, and low quality cheap materials are placed in lower layers.

Full - depth asphalt pavements are constructed by placing bituminous layers directly on the soil subgrade. This is more suitable when there is high traffic and local materials are not available.

Contained rock asphalt mats are constructed by placing dense/open graded aggregate layers in between two asphalt layers. Modified dense graded asphalt concrete is placed above the sub-grade will significantly reduce the vertical compressive strain on soil sub-grade and protect from surface water.

4.3.2 Typical layers of a flexible pavement

Typical layers of a conventional flexible pavement include seal coat, surface course, tack coat, binder course, prime coat, base course, sub-base course, compacted sub-grade, and natural sub-grade (Figure 4:1).

Seal Coat: Seal coat is a thin surface treatment used to water-proof the surface and to provide skid resistance.

Tack Coat: Tack coat is a very light application of asphalt, usually asphalt emulsion diluted with water.

It provides proper bonding between two layer of binder course and must be thin, uniformly cover the entire surface, and set very fast.

Prime Coat: Prime coat is an application of low viscous cutback bitumen to an absorbent surface like granular bases on which binder layer is placed. It provides bonding between two layers. Unlike tack coat, prime coat penetrates into the layer below, plugs the voids, and forms a water tight surface.

Surface course

Surface course is the layer directly in contact with traffic loads and generally contains superior quality materials.

They are usually constructed with dense graded asphalt concrete(AC). The functions and requirements of this layer are:

- ⇒ It provides characteristics such as friction, smoothness, drainage, etc. Also it will prevent the entrance of excessive quantities of surface water into the underlying base, sub-base and sub-grade,
- ⇒ It must be tough to resist the distortion under traffic and provide a smooth and skid- resistant riding surface,
- ⇒ It must be water proof to protect the entire base and sub-grade from the weakening effect of water.

Binder course

This layer provides the bulk of the asphalt concrete structure. Its chief purpose is to distribute load to the base course The binder course generally consists of aggregates having less asphalt and doesn't require quality as high as the surface course, so replacing a part of the surface course by the binder course results in more economical design.

Base course

The base course is the layer of material immediately beneath the surface of binder course and it provides additional load distribution and contributes to the sub-surface drainage It may be composed of crushed stone, crushed slag, and other untreated or stabilized materials.

Sub-Base course

The sub-base course is the layer of material beneath the base course and the primary functions are to provide structural support, improve drainage, and reduce the intrusion of fines from the sub-grade in the pavement structure. If the base course is open graded, then the sub-base course with more fines can serve as a filler between sub-grade and the base course. A sub-base course is not always needed or used. For example, a pavement constructed over a high quality, stiff sub-grade may not need the additional features offered by a sub-base course. In such situations, sub-base course may not be provided.

Sub-grade

The top soil or sub-grade is a layer of natural soil prepared to receive the stresses from the layers above. It is essential that at no time soil sub-grade is overstressed. It should be compacted to the desirable density, near the optimum moisture content.

4.3.1 Failure of flexible pavements

The major flexible pavement failures are fatigue cracking, rutting, and thermal cracking. The fatigue cracking of flexible pavement is due to horizontal tensile strain at the bottom of the asphaltic concrete. The failure criterion relates allowable number of load repetitions to tensile strain and this relation can be determined in the laboratory fatigue test on asphaltic concrete specimens. Rutting occurs only on flexible pavements as indicated by permanent deformation or rut depth along wheel load path. Two design methods have been used to control rutting: one to limit the vertical compressive strain on the top of subgrade and other to limit rutting to a tolerable amount (12 mm normally). Thermal cracking includes both low-temperature cracking and thermal fatigue cracking.

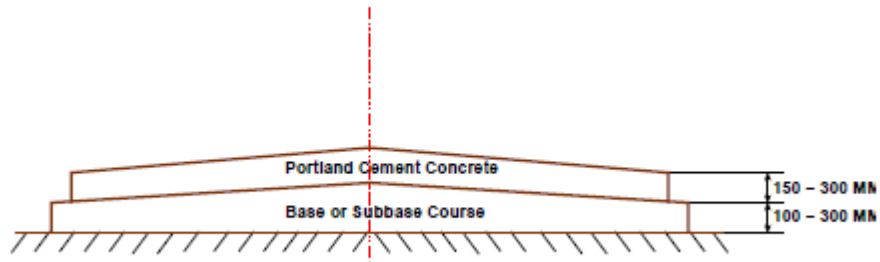


Figure 4:3: Typical Cross section of Rigid pavement

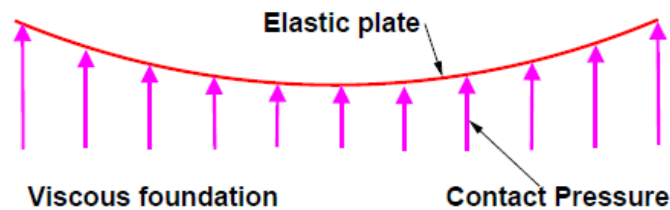


Figure 4:4: Elastic plate resting on Viscous foundation

4.4 Rigid pavements

Rigid pavements have sufficient flexural strength to transmit the wheel load stresses to a wider area below.

A typical cross section of the rigid pavement is shown in Figure 4:3. Compared to flexible pavement, rigid pavements are placed either directly on the prepared sub-grade or on a single layer of granular or stabilized material. Since there is only one layer of material between the concrete and the sub-grade, this layer can be called as base or sub-base course.

In rigid pavement, load is distributed by the slab action, and the pavement behaves like an elastic plate resting on a viscous medium (Figure 19:4). Rigid pavements are constructed by Portland cement concrete (PCC) and should be analyzed by plate theory instead of layer theory, assuming an elastic plate resting on viscous foundation. Plate theory is a simplified version of layer theory that assumes the concrete slab as a medium

thick plate which is plane before loading and to remain plane after loading. Bending of the slab due to wheel load and temperature variation and the resulting tensile and flexural stress.

4.4.1 Types of Rigid Pavements

Rigid pavements can be classified into four types:

- Jointed plain concrete pavement (JPCP),
- Jointed reinforced concrete pavement (JRCP),
- Continuous reinforced concrete pavement (CRCP), and
- Pre-stressed concrete pavement (PCP).

Jointed Plain Concrete Pavement: are plain cement concrete pavements constructed with closely spaced contraction joints. Dowel bars or aggregate interlocks are normally used for load transfer across joints. They normally have a joint spacing of 5 to 10m.

Jointed Reinforced Concrete Pavement: Although reinforcements do not improve the structural capacity significantly, they can drastically increase the joint spacing to 10 to 30m. Dowel bars are required for load transfer. Reinforcements help to keep the slab together even after cracks.

Continuous Reinforced Concrete Pavement: Complete elimination of joints are achieved by reinforcement.

4.4.2 Failure criteria of rigid pavements

Traditionally fatigue cracking has been considered as the major, or only criterion for rigid pavement design. The allowable number of load repetitions to cause fatigue cracking depends on the stress ratio between flexural tensile stress and concrete modulus of rupture. Of late, pumping is identified as an important failure criterion. Pumping is the ejection of soil slurry through the joints and cracks of cement concrete pavement, caused during the downward movement of slab under the heavy wheel loads. Other major types of distress in rigid pavements include faulting, spalling, and deterioration.

4.5 Factors affecting pavement design

There are many factors that affect pavement design which can be classified into four categories as traffic and loading, structural models, material characterization, environment. All will be discussed in detail.

4.5.1 Traffic and loading

Traffic is the most important factor in the pavement design. The key factors include contact pressure, wheel load, axle configuration, moving loads, load, and load repetitions.

Contact pressure: The tyre pressure is an important factor, as it determines the contact area and the contact pressure between the wheel and the pavement surface. Even though the shape of the contact area is elliptical, for sake of simplicity in analysis, a circular area is often considered.

Wheel load: The next important factor is the wheel load which determines the depth of the pavement required to ensure that the subgrade soil is not failed. Wheel configuration affect the stress distribution and deflection within a pavement. Many commercial vehicles have dual rear wheels which ensure that the contact pressure is within the limits. The normal practice is to convert dual wheel into an equivalent single wheel load so that the analysis is made simpler.

Axle configuration: The load carrying capacity of the commercial vehicle is further enhanced by the introduction of multiple axles.

Moving loads: The damage to the pavement is much higher if the vehicle is moving at creep speed. Many studies show that when the speed is increased from 2 km/hr. to 24 km/hr., the stresses and deflection reduced by 40 per cent.

Repetition of Loads: The influence of traffic on pavement not only depend on the magnitude of the wheel load, but also on the frequency of the load applications. Each load application causes some deformation and the total deformation is the summation of all these. Although the pavement deformation due to single axle load is very small, the

cumulative effect of number of load repetition is significant. Therefore, modern design is based on total number of standard axle load (usually 80 kN single axle).

4.5.2 Structural models

The structural models are various analysis approaches to determine the pavement responses (stresses, strains, and deflections) at various locations in a pavement due to the application of wheel load. The most common structural models are layered elastic model and visco-elastic models.

Layered elastic model: A layered elastic model can compute stresses, strains, and deflections at any point in a pavement structure resulting from the application of a surface load. Layered elastic models assume that each pavement structural layer is homogeneous, isotropic, and linearly elastic. In other words, the material properties are same at every point in a given layer and the layer will rebound to its original form once the load is removed. The layered elastic approach works with relatively simple mathematical models that relates stress, strain, and deformation with wheel loading and material properties like modulus of elasticity and poissons ratio.

4.5.3 Material characterization

The following material properties are important for both flexible and rigid pavements.

- ⇒ When pavements are considered as linear elastic, the elastic moduli and poisson ratio of subgrade and each component layer must be specified.
- ⇒ If the elastic modulus of a material varies with the time of loading, then the resilient modulus, which is elastic modulus under repeated loads, must be selected in accordance with a load duration corresponding to the vehicle speed.
- ⇒ When a material is considered non-linear elastic, the constitutive equation relating the resilient modulus to the state of the stress must be provided. However, many

of these material properties are used in visco-elastic models which are very complex and in the development stage. This book covers the layered elastic model which require the modulus of elasticity and poisson ratio only.

4.5.4 Environmental factors

Environmental factors affect the performance of the pavement materials and cause various damages. Environmental factors that affect pavement are of two types, temperature and precipitation and they are discussed below:

Temperature

The effect of temperature on asphalt pavements is different from that of concrete pavements. Temperature affects the resilient modulus of asphalt layers, while it induces curling of concrete slab. In rigid pavements, due to difference in temperatures of top and bottom of slab, temperature stresses or frictional stresses are developed.

While in flexible pavement, dynamic modulus of asphaltic concrete varies with temperature. Frost heave causes differential settlements and pavement roughness. Most detrimental effect of frost penetration occurs during the spring break up period when the ice melts and subgrade is a saturated condition.

Precipitation

The precipitation from rain and snow affects the quantity of surface water infiltrating into the subgrade and the depth of ground water table. Poor drainage may bring lack of shear strength, pumping, loss of support, etc.

4.6 Summary

Pavements form the basic supporting structure in highway transportation. Each layer of pavement has a multitude of functions to perform which has to be duly considered during the design process. Different types of pavements can be adopted depending upon the traffic requirements. Improper design of pavements leads to early failure of pavements affecting the riding quality also.

Also, as discussed taking into consideration the several factors that could affect pavement design. The most important being wheel load. Since pavements are designed to take moving loads, slow moving loads and static loads can be detrimental to the pavement.

Temperature also influences pavement design especially the frost action which is very important in cold countries.

Chapter 5

Traffic Engineering

5.1 Overview

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 flow behavior and characteristics by extensive collection of traffic flow data and analysis. Based on this analysis, traffic flow 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.

Conclusion

Transportation engineering is a very diverse and multidisciplinary field, which deals with the planning, design, operation and maintenance of transportation systems. Good transportation is that which provides safe, rapid, comfortable, convenient, economical, and environmentally compatible movement of both goods and people. This profession carries a distinct societal responsibility. Transportation planners and engineers recognize the fact that transportation systems constitute a potent force in shaping the course of regional development. Planning and development of transportation facilities generally raises living standards and enhances the aggregate of community values.

REFERENCES

- Introduction to Transportation Engineering 1.1 Tom V. Mathew and K V Krishna Rao.
- "ITE–The Transportation Profession" (<http://www.ite.org/career/index.asp>).
- "ASCE – About Civil Engineering"
(<https://web.archive.org/web/20100702022026/http://www.asce.org/ProgramProductLine.aspx?id=2147485055>). ASCE. Archived from the original (<http://www.asce.org/ProgramProductLine.aspx?id=2147485055>) on 2 July 2010.
Retrieved 28 June 2010.
- <http://www.wikipedia.com>
- [Traffic & Highway Engineering – Nicholas J. Garber & Lester A. Hoel 4th Edition](#)