Transportation Engineering

AICTE Recommended

L.R. Kadiyali

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Transportation Engineering

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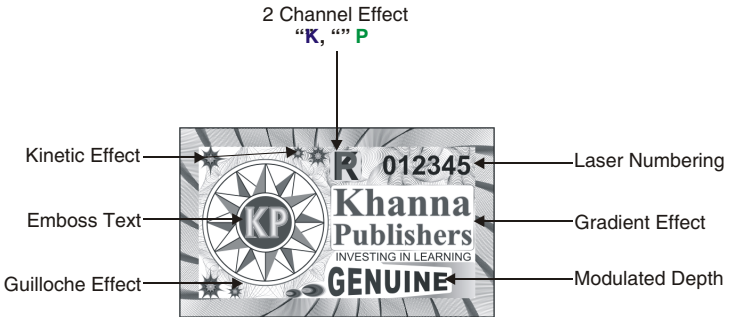

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Preface

It gives us great pleasure in presenting the new edition of Model Scheme of Syllabi for UG Engineering Degree Programmes in Civil Engineering as per based AICTE. This book "Transportation Engineering" is written in simple and lucid language.

The subject matter of book is arranged and presented such a way that the entire syllabus has been covered in article form in same sequence. In this book, we also giving the full syllabi of transportation engineering according to AICTE.

The aim of compiling this book has been to give a working knowledge of the important detail of Transportation Engineering, Highway Planning, Geometric Design of Highway, Traffic Engineering and Control Traffic Engineering, Pavement Materials, Design of Pavements, Highway Construction, Highway Drainage and Highway Maintenance and Rehabilitation.

In spite of our best support, it is possible that some errors might have crept in. We shall acknowledge with gratitude, if any such error is brought in our notice.

Also, any suggestions and comments from students and teachers for improvement of the book are welcome.

We hope the book will be found useful by the readers.

—Author

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CHAPTER

Highway Planning and Classification

1.1. ROLE OF TRANSPORT IN MODERN SOCIETY AND A COUNTRY'S ECONOMY

1.1.1. Transport and Economic Growth

Transport is a key infrastructure of a country. A country's economic status depends upon how well served the country is by its roads, railways, air ports, ports, pipelines and shipping. The rate at which a country's economy grows is very closely linked to the rate at which the transport sector grows. In India's case, it has been found that while the economy grows at a certain rate, say r% per annum, road transport has grown at 2r%. The multiplier (2 in this case) is commonly known as the Elasticity of transport demand with respect to GNP. India's economy grew at around 3.5% during 1951–2010, and road transport grew at around 7.5% during that period. Since 1980, the economic growth has been around 5%, and the road transport growth was around 10%. As India is now poised for a 8–9% economic growth, road transport can be expected to grow at 12–14%, even assuming the elasticity coefficient to be 1.5.

The per capita GNP and the car ownership rate of selected countries, shows how the country's economy and transport are closely inter-related.

1.1.2. Place Utility of Goods

In any country, the natural resources are not evenly located. For example, coal is concentrated in the eastern belt of Orissa-Bihar-Bengal in India. In the coal belt, the marginal utility of coal is low whereas in a far-off region, its marginal utility is high. Transport gives "place utility" to the goods.

1.1.3. Time Utility of Goods

Transport minimises the time for the movement of people and goods. Thus, transport gives time utility to economic activities.

1.1.4. Transport Overcomes the Separation Between the Producer and the Consumer

The production of goods and their consumption do not always take place at the same place. For example, Punjab produces surplus grains, which are consumed in the remote corners of India. The separation between the producer and the consumer is overcome by transport.

1.1.5. Preservation of Quality of Goods

Certain goods like vegetables, fruits, milk and fish are perishable. They have to be quickly moved from the production centres to the consumers. Transport enables the quick movement to preserve the quality of such goods.

1.1.6. Economies of Scale and Specialisation

The modern world economy is characterised by specialisation and mass production to achieve economies of scale. Transport enables this to take place. Thus, South Korea may mass produce computer monitors to be shipped to different countries for being assembled as personal computers. This is rendered possible through transport.

1.1.7. Exploitation of Natural Resources

Most developing countries depend on export of raw materials as the backbone of their economy. India is a traditional exporter of coffee, tea and spices. The Middle East countries export petroleum. Transport is the medium for exploitation of natural resources.

1.1.8. Transport and Urbanisation

Urbanisation and economic development go together. Rapid urbanisation can take place only if a country has a good transport network.

1.1.9. Transport and Industrial Development

Industrial activity depends on a good system of transport for moving the raw materials and finished goods. Certain areas in India have remained backward industrially since they do not have a good transport system.

1.1.10. Transport and Agricultural Development

Agriculture depends on a good transport system for supplying inputs like seeds, fertilisers, farm machinery and labour. Also, a good transport system enables the farm produce to reach the markets at the least cost.

1.1.11. Cost of Goods

A major component of the cost of goods is the transport cost. A good transport system results in lower transport costs and thus a lower cost of goods. A country with a poor transport infrastructure loses its competitive edge in exports as its goods get edged out in prices in the world market.

1.1.12. Administration

A good network of roads and railways facilitates administration.

1.1.13. Defence and Strategic Needs

For the defence and strategic needs of a country, an efficient transport network is vital.

1.1.14. Tourism

Tourism, both domestic and international, can prosper only if the country has a good transport system.

1.1.15. Transport Facilitates Social Activities

Social activities like education and health can take place if the region has a good transport network. The backwardness of certain regions in India in terms of literacy, life expectancy and infant mortality can be traced to the lack of road accessibility to the villages.

1.1.16. The Example of America

America is a classic example of how a transport system can build the nation. During the latter half of the nineteenth century, America built its railroads and this led to its settlement

pattern and industrial development. With the advent of the motor vehicle, America invested heavily on its roads, and transformed itself as the leader of the world economy.

1.2. MODES OF TRANSPORT AND THEIR CHARACTERISTICS

1.2.1. Transport Modes and their Characteristics

The important modes of transport are :

1. Railways
   - — Surface
   - — Elevated
   - — Underground (Tube)
   - — Light Rail Transit (Tram)
2. Road Transport
3. Air Transport
4. Water Transport
   - — Coastal shipping
   - — Inland water transport
   - — International shipping
5. Pipe Lines
6. Rope ways

The efficiency of a transport mode can be judged in terms of the following characteristics:

1. Speed
2. Safety
3. Adequacy
4. Frequency
5. Regularity
6. Integration
7. Responsibilities
8. Cost
9. Cheapness
10. Fuel efficiency
11. Employment generation.

Speed is the essence of transport. It reduces overall cost, reduces storage and inventorying, helps a faster turn-around with existing facilities and is of prime importance for perishable commodities.

Safety for passengers demands highest possible standards of construction, maintenance and operation. For goods, safety implies protection against theft, fire and damages.

Adequacy represents the capacity of a mode to transport people and goods.

Frequency is an important characteristic of transport. It is related to capacity, consolidation and storage. Assured frequency attracts people and goods.

Regularity is the punctuality of the service and its ability to adhere to published schedules. A regular service inspires confidence in the clientele.

Integration denotes where the mode involves transfer from one system to another or involves transaction with a single undertaking or multiple undertakings. A system with few transfers and operated under a single undertaking is the most efficiently integrated system.

Responsibility denotes the ability to meet liabilities or compensation for loss or damage. A government undertaking is generally more responsible than a private one. Usually, every system has legislation to cover regulation of transport.

Comfort is essential for passenger transport.

Cheapness is the main consideration for consumer preference. Cheapness should be calculated not only on the operating cost, but on the total resources cost, including cost of initial facility construction, cost of maintenance of the facility and the cost of operation.

The global energy crisis has prompted transport planners to select modes and systems which are the most fuel-efficient.

In under developed and labour-surplus economies, employment generation is an important consideration. Transport modes like roads and road transport are known to generate high levels of employment.

1.2.2. Comparative Advantages and Disadvantages of Different Modes

In light of the criteria laid down above, the various modes can be evaluated as under :

Speed. Table 1.1 gives the speeds that are generally associated with each of the modes :

Table 1.1. Speeds of Various Transport Modes

S. No.	*Mode*	*Normal Speed Range in India (km/hr)*	*Remarks*
1.	Railway	50–120	(1) Speed depends on gauge and number of tracks (2) Speeds upto 250 km/hr are possible (*e.g.* New Tokaido line in Japan)
2.	Road transport cars Buses and trucks Two-wheelers Cycles Autorickshaw Bullock cart	50–100 30–80 25–50 8–15 15–30 3–5	Speed depends on pavement width and terrain. Values given are for good roads in plain terrain.
3.	Air transport Boeing 747 Boeing 707 Feeder aircraft	 1000 950 300–400	
4.	Water transport Ocean liners Coastal ships Inland water barges	 35–55 15–35 10–25	
5.	Pipe lines	5–10	
6.	Ropeways	5–10	

It is seen that air transport is the fastest and is about 10–20 times faster than road and railway transport.

Safety

Rail transport moves on single exclusive track, and as such, if adequate measures are taken to ensure safety at crossings, Railways are reasonably safe. Modern systems of electronic signal control and safety devices have further enhanced the safety of rail travel. But, if an accident take place, the death toll in the mishap is generally heavy.

Adequacy

The railways can meet seasonal fluctuations in traffic, but generally capacity is wasted as a rule. Due to limitations of number of wagons and carriages that can be hauled by a train and the number of trains that can be handled on the track, the carrying capacity is restricted by gauge, number of tracks and traction device (Table 1.2).

Table 1.2. Capacity of Railway Track

Type of track	*Number of trains/day*
Single track	20–30
Double track, with manual track control	60–80
Double track, with centralised track control	160–200

In India, super fast express trains consist of over 20 coaches and carry over 1500 passengers. Double traction engines can enhance the number of coaches that can be hauled. For urban mass transit, Metros and Rapid Transit Systems can accommodate trains with a headway of 2 minutes, thus carrying upto 60,000 persons/hour/direction. For light rail transit, capacities upto 20,000 persons/hour/direction are possible. Exclusive busways can carry upto 40,000 persons/hour/direction. Goods trains can haul about 50–60 wagons. The pay load of a wagon is in the range of 50–80 Tonnes. (The BOX car carries a load of about 55 Tonnes in India). Thus, a typical Indian goods train can haul 3000 Tonnes of goods.

The capacity of roads is governed by the pavement width and terrain. In plain terrain, the capacity of roads under Indian conditions is given in Table 1.3.

Table 1.3. Capacity of Indian Roads

Pavement width	*Design Capacity in PCUs/day*
Single lane	2000
Intermediate lane	6000
Two lane	15,000–17,500
Four lane (divided)	35,000–40,000

Note : PCU signifies passenger car unit (refer to Table 1.6).

An average bus has a carrying capacity of 50 sitting and 10 standing passengers. A passenger car can carry 5 persons including the driver. On city streets with mixed traffic, buses can carry upto 10,000 persons/hour/direction. Beyond this range, exclusive bus lanes or Light Rail Transit (LRT) or Metros become necessary. An average single unit truck, by far the most common in India, is permitted to carry a pay load of 10 Tonnes. Overloading (up to 15 Tonnes) is very common. Truck-trailer combinations can carry pay loads of 25 Tonnes easily, but have yet to become popular in India. The advantage of road transport is that it is most versatile and adaptable when considering capacity. Depending upon the load offered, any number of vehicles can be pressed into service or withdrawn.

The capacity of barges and ships are given in Table 1.4.

Table 1.4. Capacity of Barges and Ships

Small barge	*100–400 Tonnes*
Large barge	1000–2000 Tonnes
Coastal ships	3000–20000 DWT
Ocean liners	150,000 DWT for berths
(*a*) Crude oil	300,000 DWT for Single Point Moorings
(*b*) Dry bulk	150,000 DWT
(*c*) Containers	Feeder Vessels : 600 TEUs
	Main Line Vessels : 2000–3000 TEUs
Note :	
DWT	Dead Weight Tonnage
TEU	Twenty Feet Equivalent Unit

The handling capacity of ports and harbours is a mojor bottleneck when considering ocean going liners. The port capacity is governed by a number of factors such as (*i*) number, depth, length and layout of berths (*ii*) size of ships and the pattern of their arrival (*iii*) approach channels and locks (*iv*) port facilities (*v*) open space (*vi*) warehousing space etc. A berth occupancy rate of 67 percent is considered to be an efficient norm. The capacity of a modern berth is given in Table 1.5.

Table 1.5. Handling Capacity of Port Berth

Type of berth	*Handling capacity per year*
1. General cargo	
(*a*) Break bulk	60,000 T
(*b*) Neo-bulk (steel, auto etc)	200,000–400,000 T
2. Dry bulk	300,000–1,000,000 T
3. Containers	100,000–150,000 TEUs
4. Petroleum	1.5–6.0 million T
5. Liquid bulk other than petroleum	80,000 T

The seating capacity of some of the modern aircraft is given in Table 1.6.

Table 1.6. Seating Capacity of Air-craft

Type	*Maximum Passengers*
1. Douglas DC–4	86
2. Caravelle	139
3. Boeing 707	179
4. Boeing 737	130
5. Boeing 747	490
6. Airbus A–300	345

The capacity of an air-port terminal depends upon a number of factors such as layout, number of docking berths, baggage handling facilities, baggage checking arrangements, security checking arrangement, number of checking-in counters, instrumentation for controlling air-craft landing and take-off, number of run-ways, area of taxiways and apron etc. The practical annual capacity of a single runway with modern facilities is in the range of 170,000 to 215,000 air-craft landings and departures per year.

The capacity of a pipe line depends upon its size and the material handled. Solids in a slurry-form are increasingly being handled by pipe lines. A simple 50 cm dia pipe line can handle about 250 tonnes of solids per day.

Frequency and Regularity

Almost all modes of modern transport offer regular, frequent and assured service. Freight transport by road in India is in private hands and is known for its better service than railways in matters of frequency and regularity.

Table 1.7. Energy Efficiency of Various Transport Modes

S. No.	*Passenger*	*Energy for Propulsion BTU/Pass-km*
1.	Electric traction—railway	54.6
2.	Diesel traction—railway	151.2
3.	Steam traction—railway	1445.8
4.	Diesel bus	288.7
5.	Petrol bus	526.5
6.	Average car	1909.0
S. No.	*Freight*	*BTU/Tonne-km*
1.	Electric traction—railway	84.6
2.	Diesel traction—railway	255.5
3.	Steam traction—railway	3576.9
4.	Diesel truck	1587.3
5.	Barge	328.0
6.	Pipe line	281.7

In terms of consumption of fuel in litres, the comparison is presented in Table 1.8.

Table 1.8. Energy Intensity of Different Modes

Mode (*a*) *Passenger*	*Energy requirement in Litres per Passenger seat-km*
1. Air bus	0.042
2. Boeing	0.055
3. F-27 Turbo prop	0.075
4. HS 748 Turbo prop	0.80
5. Car (4 seats)	0.025
6. Bus (52 seats)	0.0048
7. AC Railway berth	0.016
8. Second class Railway sleeper berth	0.0031
(*b*) *Freight*	*Litres per tonne-km*
1. Rail transport	0.0076
2. Heavy road vehicle	0.033–0.066
3. Light road vehicle	0.104

It is seen that the air transport is the most fuel consuming mode. In order of declining rates are road, rail, inland water transport and pipe line.

Employment Generation

India is a country with a big unemployment problem. Transport is a sector which absorbs labour force in good measure. Any mode of transport that offers the best employment potential, therefore, should find favour. A recent study in India has yielded valuable results in this area, as shown in Table 1.8.

It is thus seen that road transport, inland water transport and coastal shipping score very high as compared to railways and air transport in the matter of employment generation.

1.2.3. Transport Modes of India

The various transport modes discussed earlier have been developed to different levels in India.

Railways have a route length of 62,500 km and are the principal transport mode. They handle 300 billion passenger kilometers per year, which is 20 percent of the total road rail passenger traffic. The freight traffic handled is 257 billion tonnes per annum which is 40 per cent of the total road rail freight traffic.

Road transport has been growing very fast in the past and has been eroding into the passenger and freight traffic carried by the railways. This trend is evidenced in other countries too. The reasons are the many advantages offered by the road transport over the railways. The total road length in India is over 3 million km, of which about half is surfaced. The total length of National Highways is about 79,243 km. The number of motor vehicles in India is about 67 million, the annual growth rate being about 10 percent. In addition there are nearly 15 million bullock carts in the country and a large number of bicycles (about 45 million).

India's public sector airline is now known as Air India, which handles both domestic and international traffic. There are several private airlines, which operate mainly in the domestic sector, though some also operate on international routes. They carry 80 percent of the civil air traffic in the country now. Domestic air traffic has been increasing at a rate of around 10 percent per annum.

India has a coast line of 5,660 km and hence the potential for coastal shipping is enormous. There are 176 ports, 10 of them being major and 23 intermediate. Coastal shipping has, however, not grown as it should have been.

The total length of navigable inland waterways is 14,500 km consisting of rivers, canals, creeks, backwater and tidal inlets. Due to lack of development, only 5200 km of river water ways and 485 km of canals are suitable for mechanised crafts. There is thus a great scope for improvement in future.

There are quite a few pipe lines for carrying oil and a few for carrying slurries. Aerial ropeways are few.

1.2.4. A Review of Transport Systems and Technology

The transport systems and technology have undergone great changes in the past. The invention of the wheel was the real beginning of the process. Landmarks in the development are the invention of the steam engine and invention of the internal combustion engine. These opened up new forms of wheeled transport ranging from the motor car, the railway, the cycle, the motor cycle and so on. At the present, the wheeled vehicles travelling on land surface are the predominant transport system. The steam engines transformed the old ships with sails into self-propelled carriers. The aircraft also developed from the internal combustion engine.

Innovations in vehicle technology include the air-cushion vehicle which eliminates the traditional wheel. Hydrofoil boats and aircraft use airfoil to create uplift forces.

Developments in Personalised Vehicle Systems

The personalised motor car has grown in popularity because of great advantages it has over other forms of transport systems. But problems of fuel shortage, congestion, parking, environmental pollution etc. have hampered the further development of this system. Research is, however, continuing to develop more efficient personalised vehicle systems.

The automated highway is one such technology. It consists of a specially designed carriageway with control cables embedded in the pavement. The operations normally performed

by a driver, such as speed selection and adjustment of space between successive vehicles would be handled by a centralised computer. It is reported that a capacity of 9000 vehicles/hour/lane is possible with this system.

A dual-mode system consists of a small personalised car, capable of moving on roads as well as on rail lines. When on rails, they are automatically driven and controlled. The Star RR car and the Automobile are examples of this technology.

Battery-powered small cars offer new power source and are likely to be popular in future.

Developments in Bus System

Because of many advantages, (such as lower fuel consumption, lesser congestion on the roads, lesser pollution) bus transport offers a promising future. Exclusive bus lanes have been introduced with good results in many cities. A capacity upto 40,000 seats per hour or 550 buses per lane per hour is possible on exclusive bus lanes.

Electric trolley buses (ETB) are likely to become popular in the future because of the absence of pollution and use of non-oil based fuel for propulsion.

The disadvantages of ETBs are their reduced manoeuvrability and the aesthetic intrusion caused by overhead power lines.

Chartered buses (subscription buses) are becoming increasingly popular in big cities since they cater to fixed time commuter travel on established corridors.

Dial-a-bus is a demand responsive bus system, whereby a group of passengers can dial for a bus which operates on an exclusive bus lane.

Mini-buses can be profitably employed in congested Central Business Districts (CBDs).

Development in Rapid Rail Transit

Railway transit is a well-known means of rapid transit along high density corridors. Railways can be :

(*i*) Surface

(*ii*) Underground or

(*iii*) Elevated

Surface rapid rail transit serves an important role in Mumbai, Chennai and Delhi. The lines are electrified. An underground system between Dum Dum and Tollygunge has been built at Kolkata; the line is 16.4 km long and has cost about ₹ 1000 crores. Delhi metro has completed some sections and more are being planned. The Master Plan for Metro rail envisages construction of a length of 244 km. The average cost per Km is around ₹ 200 crores. There are plans for Metros for Bangalore and Hyderabad.

Rapid developments have taken place in the technology of rapid rail systems in the recent past. Elevated guideways with backed air-cushion vehicles hold good promise. Speeds upto 300-500 km/hr might become possible. Even in the conventional steel rail systems, technological developments are promising. The New Tokaido line of the Japanese system is an example of this, where a maximum speed of 250 km/hr is achieved. The monorail system is another variety of rapid rail transit. The ALWEG system is an example, wherein rubber tyred vehicles straddle a concrete box beam. The SAFEGE system of monorail hangs underneath the rail and has rubber tyres.

1.2.5. Light Rail Transit

Light Rail Transit (LRT) is also popularly known as the tram or the street car. Trams used to operate on the roads of Delhi and Mumbai, where they have now been discontinued.

They, however, continue to run in Kolkata. The word 'light rail' refers not so much to the strength of the rail, but to the lighter cars, shorter trains and methods of operation.

A resurgence in the popularity of this mode is now visible in some cities of the world. The reasons are :

(*i*) The fuel crisis has made the oil-based bus transport system costly. The tram is an electricity based system and is thus free from the uncertainties associated with availability of oil.

(*ii*) Trams are relatively cheaper than conventional suburban rail systems.

(*iii*) Trams are free from the pollution caused by the motor vehicles.

(*iv*) Trams are suitable for pedestrian malls.

Some of the cities which have introduced the LRT are ; Boston, Buffalo, New Orleans, Cleveland, New York, Philadelphia, Pittsburg, Sacramento, San Diego, San Francisco, Montreal, Toronto, Vancouver, Buenos Aires, and Oslo.

Magnetic Levitation (Maglev) System

Maglev is a rail system running on monorails and capable of running at as high speeds as 400 km/hr. The technology has been developed sufficiently to make the operation commercially feasible.

The technology is based on the principle of magnetic levitation. Entire trains are suspended and propelled forward by magnetic forces without touching the rail track. A line 0.6 km long is already operational between the airport and the railway station in Birmingham (U.K.). Germany has also developed a system called Transrapid.

The advantages claimed are :

(1) Tracks require less maintenance (2) High speeds are possible

(3) Low noise.

The cost of constructing a single track is around $ 3-4.5 million per km.

Para-transit

Para-transit is a new term which has come into use and is intended to cover some transport systems which are intermediate between the personal transportation system and the mass transportation system. The following systems fall under this group :

(*i*) Car-pooling (*ii*) Van-pooling

(*iii*) Dial-a-ride taxi service (*iv*) Dial-a-bus

1.2.6. Need for Coordinated Development

All modes of transport have their own role to play. This should be clearly recognised in national transportation planning. No single mode should be allowed to develop at the cost of any other or to the detriment of the nation's economy. A coordinated approach is called for.

1.2.7. Multi-modal Tansport Systems

Modern day transportation covers more than one mode. For example, the goods produced in a factory are packed into a container and moved by road to an Internal Container Depot (ICD) or Container Freight Station (CFS). From there, it is moved by rail to a port and then on, it travels by ship. This system is known as multi-modal or inter modal transport. The containers have rendered this system to flourish.

Another example of multi-modal transport is the "piggy-back" system or trailer-on-flat-car (TOFC), wherein the trailer of a truck is moved on flat rail wagons over long distances.

Transportation Engineering

About the Book

This book "Transportation Engineering" is based on AICTE syllabus. It contains separate chapters on Highway Planning and Classification, Geometric Design of Highways, Traffic Engineering, Pavement Materials, Highway Construction and Highway Drainage.

This book provides a Multi-disciplinary coverage to suit to the requirements of engineers, planners, statisticians, administrators and so on. The interest in the subject is growing in our country is obvious from the fact that many universities in our country are offering undergraduate courses in Highway and Traffic Engineering. It will serve as a textbook during their academic career and a reference for their professional career.

Contents

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- Highway Maintenance and Rehabilitation

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