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GUIDELINES FOR TRAFFIC FORECAST ON HIGHWAYS

(First Revision)

INDIAN ROADS CONGRESS
2015

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FOR
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GUIDELINES FOR TRAFFIC FORECAST ON HIGHWAYS

1 INTRODUCTION

This guideline is intended for use by traffic engineers/planners to forecast traffic on highways and inter-urban roads. This document is structured in **Three Sections. Section A** describes the basic concepts and gives a brief overview of the forecasting process. **Section B** highlights the methodological aspects related to traffic forecasting on inter-urban roads/highways. In **Section C**, several example problems are provided to help traffic engineers/planners to carry out project specific calculations in a similar manner.

The revised draft Guidelines for Traffic Forecast on Highways, IRC:108-2014 was prepared by the Sub-group comprising Dr. Bhargab Maitra, Dr. M.R. Tagore, Dr. S. Velmurugan and Dr. P.K. Sarkar. The Committee deliberated on the draft revision in a series of meetings. The Transport Planning and Traffic Engineering Committee (H-1) approved the draft revision in its meeting held on 26.07.2014 for placing before the Highways Specifications & Standards Committee (HSS).

The composition of the H-1 Committee is as given below:

LIST OF ABBREVIATIONS

ADT	:	Average Daily Traffic
AADT	:	Annual Average Daily Traffic
ARMA	:	Autoregressive Moving Average Model
ARIMA	:	Autoregressive Integrated Moving Average Model

DMA	:	Double Moving Average
GDP	:	Gross Domestic Product
IRC	:	Indian Roads Congress
LCV	:	Light Commercial Vehicle
LOS	:	Level of Service
MADT	:	Monthly Average Daily Traffic
MAV	:	Multi-Axle Vehicle
MNL	:	Multinomial Logit
MoRT&H	:	Ministry of Road Transport and Highways
NDDP	:	Net District Domestic Product
NHAI	:	National Highways Authority of India
NL	:	Nested Logit
NSDP	:	Net State Domestic Product
O–D	:	Origin – Destination
PCI	:	Per Capita Income
PCU	:	Passenger Car Unit
PHF	:	Peak Hour Factor
PIA	:	Project Influence Area
PWD	:	Public Works Department
RP	:	Revealed Preference
TC	:	Travel Cost
TT	:	Travel Time
2T-HCV	:	2 Axle Heavy Commercial Vehicles

The HSS Committee approved the draft revision in its meeting held on 9th August, 2014. The Executive Committee in its meeting held on 18th August, 2014 approved the draft revision for placing it before the Council. The IRC Council in its 203rd meeting held at New Delhi on 19th and 20th August, 2014 approved the draft revision of IRC:108 "Guidelines for Traffic Forecast on Highways" for publishing.

SECTION : A

BASIC CONCEPTS AND OVERVIEW OF FORECASTING PROCESS

A.1 Need for Traffic Forecasting

All projects relating to roads and highways need the fundamental input of traffic volume to be catered for by the facility. This is true for any present day analysis or assessment of the facility in future date. Therefore, it is imperative that a traffic forecast is necessary to evaluate the case on a future date.

Any forecast will be as good as the data that are used as input to the forecasting method and process. Thus, forecast cannot be considered to be totally accurate and forecasts for longer horizons need to be reviewed and revised with the progression of time using the available data progressively. Also, this is a function of the method used and disaggregation used in the forecasting process.

Therefore, all designs, analysis and evaluation related to roads and highways shall require traffic forecasts as input. So much so, the economic and financial viability of projects are largely ruled by the traffic forecast.

A.2 Basic Terminologies

In the context of traffic forecast on highways, several terminologies are used. These terminologies are defined below:

Average Daily Traffic (ADT): The total volume of traffic passing a point or segment of a roadway during a given time period (more than a day and less than a year) divided by the number of days in that time period.

Annual Average Daily Traffic (AADT): The total volume of traffic passing a point or segment of a roadway during one full year divided by the number of days in the year.

Base Year: It is the year when all primary traffic surveys are carried out. Base year is also that year beyond which traffic projections are carried out.

Capacity: The maximum sustainable hourly flow rate at which persons or vehicles reasonably can be expected to traverse a point or a uniform section of a lane or roadway under prevailing roadway, environmental, traffic and control conditions.

Control Count Stations: Control count stations are selected representative locations where classified volume counts are carried out over the complete survey period to measure and quantify variation of traffic volume patterns.

Coverage Count Stations: Coverage count stations are those locations where classified volume counts are carried out only for a part of the complete survey period. Each coverage count station shall have a representative control count station to establish variation in traffic volume pattern over the complete study period.

Design Hourly Volume (DHV): It is that hourly volume in a year which is used to judge the capacity requirement. DHV is normally taken as 30^{th} highest hourly volume, which means that only for 29 hours in a year the traffic volume can exceed the design volume.

Design Period: The period in future for which the road is designed.

Directional Distribution: A characteristic of traffic, that the volume may be greater in one direction than in the other during any period on a highway. Directional distribution indicates the percentage distribution of total traffic in two directions of travel. This is more relevant for undivided roads and an important input for capacity analysis and pavement design.

Forecast Period: The total length of time span covered by the traffic forecast. It is equal to the difference between the end year of the design period and the base year.

Horizon Year: The future years to which a planning activity is directed, which may be more than one. The traffic volume forecast is also done for each horizon year.

Level of Service (LOS): A quantitative stratification of a performance measure or measure that represents quality of service, measured on an A to F scale, with LOS-A representing the best operating conditions from the traveler's perspective and LOS-F the worst.

Peak Hour Factor (PHF): The hourly volume during the analysis hour divided by the 4 x peak 15-minute flow rate within the analysis hour. The PHF is also considered as a measure to estimate traffic demand fluctuations within the peak hour. (The use of PHF is remote in case of highway traffic analysis, unless intersections are considered).

Peak Hour Proportion (PHP): The volume of traffic during the peak hour (highest hourly volume in a 24 hour day) expressed as percentage of total 24 hour traffic volume in a day. This is normally used for reverse calculation of daily traffic volume from peak hour volume estimated from traffic survey for a shorter duration than 24 hours.

Project Influence Area (PIA): The geographical area where the impact of the upcoming proposed highway development will be predominant. Alternatively, it is also the geographical area the development of which will influence the traffic of the specific highway project. The socio-economic profile of the PIA is expected to have influence on the traffic volume of the project corridor.

Seasonal Factor: Seasonal Factors consider variation of travel demand during different months or seasons in a year. Generally, these factors are estimated based on data from permanent traffic count stations. But, in absence of such data, secondary data like petrol and diesel sales data along the project corridor may be used to formulate the seasonal factors.

Service Flow Rate: The maximum directional rate of flow that can be sustained in a given segment under prevailing roadway, traffic, and control conditions.

Traffic Analysis Zone (TAZ): The basic geographic unit for inventorying demographic data and land use within a study area. The size and shape of TAZs can influence model results. Highway trip loadings and the percent of intra-zonal trips are directly impacted by study area zonal detail and the size of the zone.

A.3 Design Period

The design period may vary from one project to another. In majority of road projects, the design period may be taken as 15 or 20 years. It is important to specify the design period, since traffic volume forecasts are required from the starting year to the end-year of the design period. The growth of traffic may not be uniform throughout the design period due to various reasons. A common practice of dividing the design period into suitable time spans (with intermediate horizons) and estimation of the growth factors for each time span may be adopted, and the traffic volume forecast at the end of each time span be reported. For example, if the base year for a project is 2013, and the design period is 20 years, and if the road is expected to be opened to traffic in 2017, then traffic forecast is necessary up to horizon year 2037. If the design period is divided into four equal time span, then traffic forecast may be reported for horizon years like 2019, 2024, 2029, 2034 and 2039. Thus, the growth factors may be reported for different time span so that it is possible to calculate the traffic volumes even at intermediate years.

A.4 Stage Construction

As the traffic volume continues to grow over years, the capacity requirement to maintain a minimum LOS may vary during the design period. If the variation of capacity requirement is equivalent to that of additional traffic lane(s), then a stage construction may be planned to optimize the utilization of financial resources. For example, traffic volume forecast for an existing 2-lane road may indicate a requirement of 4-lane dual carriageway in 2019 and a 6-lane dual carriageway in 2029. In such a situation, a stage-wise construction plan may be developed as per the requirements.

A.5 Mid-Blocks and Intersections

For highways, the mid-block traffic volumes govern the capacity requirement, pavement design, etc. Highways also include intersections and hence the appropriate design of these intersections is essential for safe and efficient movement of traffic. This implies that the, highway projects shall require traffic studies for mid-blocks as well as intersections. Intersection traffic volumes can also be used for deciding the nature of control (say, uncontrolled, rotary, grade separated, etc.) required at the intersection.

A.6 Components of Traffic Forecast

For forecasting of traffic in the future, it may be necessary to estimate separately various components of traffic namely normal traffic, generated traffic and developmental traffic.

Normal Traffic: Normal traffic is the estimated traffic on a roadway facility due to increase in population, natural change in land-use and normal socio-economic development in the region or PIA. The normal growth should be estimated based on the past and envisaged future growth trend of traffic on the project corridor or in the influence area. Normal traffic growths are expected to be higher for uncongested operations but the growth rate declines with increase in congestion level, reaching a self-limiting equilibrium.

Generated Traffic: Road improvements may attract trips from other routes, modes and encourage longer and more frequent travel. The additional traffic volumes likely to be generated on project corridor due to road improvements are termed as generated traffic. Generated traffic may be classified further as diverted traffic and induced traffic.

Diverted Traffic: It is that component of generated traffic which is the result of shift in route and change of mode. Diverted traffic could be both positive and negative.

Induced Traffic: It may be defined as an increase in total vehicle-kilometers of travel due to roadway improvements, which may be due to increase in vehicle-trip frequency and distance, but exclude trips/traffic shifted from other routes. It is like release of latent demand for travel.

Generated traffic reflects the economic “law of demand,” which states that consumption of goods increase as the price declines. Roadway improvements, that alleviate congestion and reduce generalized cost of travel, encourage more travel/vehicle use. Depending upon the road network and socio-economic profile of the PIA, generated traffic may constitute a significant part of the total future traffic volume.

Developmental Traffic: In some cases, there may be large scale developments in the PIA of the proposed project corridor. Such developments may be industrial, commercial or even residential, and they may generate a substantial amount of additional traffic and contribute significantly to the future traffic volumes on the project corridor. Developmental traffic may not be relevant in all projects. Wherever it is relevant, the traffic engineer/planner should consider this component for obtaining a realistic forecast of total traffic.

In principle, total traffic forecast for the horizon year should be inclusive of all components of traffic, i.e., normal traffic, generated (diverted plus induced) traffic and developmental traffic. In all road projects (say, two-lane to four-lane or four-lane to six-lane) normal traffic forecast is mandatory. However, generated and developmental traffic are project specific and should be considered for total traffic forecast when they are contextual. For example, if there is a competing road or rail corridor then the traffic forecast on the project corridor cannot be done without considering the influence of the competing corridor and in such cases it will be necessary to duly consider the component of generated traffic. Similarly, if a new township or settlement is planned in the PIA then it would be necessary to estimate the developmental traffic while forecasting the total traffic on the project corridor. The traffic engineer/planner may estimate generated and/or developmental traffic, if these are found to be relevant and significant for the project. If generated and/or developmental traffic are excluded, the traffic engineer/planner should justify the reasons for exclusion.

A.7 Impact of Toll on Traffic Volume

In India, over the last decade, many highways have been developed as toll roads on the principle of “user pays” to meet the cost of the road construction and maintenance through toll revenues. While road development is likely to have positive impacts on traffic growth, the toll charges is likely to have a deterrent effect on the traffic growth. Traffic volume on the proposed project corridor is likely to be lower than normal case when the corridor is operated as a toll road, when there are competing routes. Hence, it is necessary to duly consider the effect of toll on various components of traffic forecast in order to have a realistic assessment of traffic volumes. It may also be noted that accurate traffic volume forecast is of critical importance as the forecast influences the financial viability of toll road projects.

A.8 Highways Passing through Urban Areas

Whenever highway passes through urban/suburban area, the section of highway experiences the movements of local as well as regional and through traffic. Local or Urban Traffic is that component of traffic which is internal in nature (i.e. Internal-Internal). Regional traffic constitutes the traffic which is internal-external and external-internal in nature. Through traffic constitute vehicles having both origin and destination outside the study area or the core PIA and is therefore, external-external in nature. Generally, the growths of these types of traffic are different from each other. Therefore, when a significant length of highway is passing through urban/suburban area and a separate forecast is necessary for the section of the highway, it is necessary to appreciate the nature and magnitude of these types of traffic and work out separate growth factors for each type of traffic to forecast the overall growth of traffic. The contribution of various types of traffic in the ADT may be obtained from the O-D data.

A.9 Traffic Forecasting Process and Steps

The steps in traffic forecasting process for rural highways are shown in a flowchart given in **Fig. A.1**. There are three major stages that should be considered in traffic forecasting on rural highways. **Stage-1** (may be called as preparatory works) includes activities pertaining to the preliminary understanding about the proposed project corridor and its role in the influence area or regional development. **Stage-1** also provides significant assistance in carrying out various tasks in **Stage-2** (may be called as analysis of base year travel) and **Stage-3** (may be called as forecasting of travel). **Stage-2** includes detailed understanding of the travel along the project corridor in the base year. It consists of the field data collection and analysis of base year data. Secondary data (socio-economic data) pertaining to factors which usually influence the overall travel scenario of the PIA should also be collected and analyzed at this stage. **Stage-2** also involves the estimation of base year traffic to be used in forecasts for horizon years. In **Stage-3**,the growth rates are to be determined with possible disaggregation of base year data and duly considering various factors which influence the growth of traffic in the project corridor. The details of the steps, to be followed in various stages are shown in **Fig. A.1** and explained in the succeeding section.

A.9.1 *Study of the Base Year Transport Network*

It is necessary to study the transport network map in the proposed project corridor, which will highlight the different components of transport network, viz. roadway network, railway network and shipping infrastructures if any, within the PIA. Functional and operational classification of the transport links should also be presented categorically. Carriageway configuration of different road links should be highlighted in the map. It should also consider the existence of the human settlements. The study of the transport network would give an understanding about role of the proposed project corridor in the PIA. Alternate routes and/or alternate transport facilities should also be identified in this step.

A.9.2 *Reconnaissance Survey*

Reconnaissance survey needs to be conducted to understand the base year travel, land-use along the corridor; and identify the major intersections which act as points of diversion/ feeders for the highway traffic. A basic understanding of the travel pattern of passenger and goods traffic needs to be obtained at this stage. The influence of the local traffic also needs to be observed along the corridor to decide judiciously the primary survey locations and formation of TAZs.

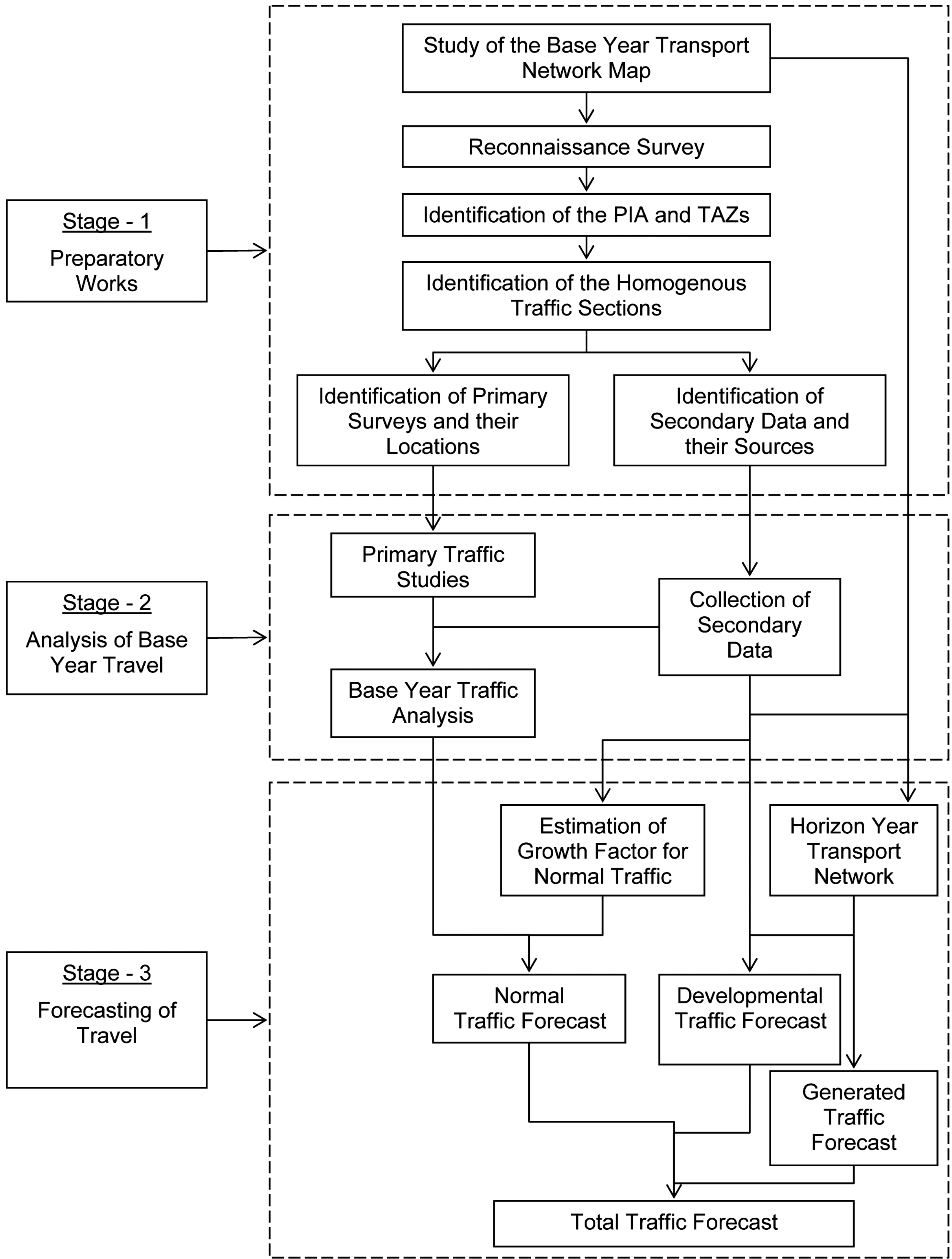

Fig. A.1 Traffic Forecasting Process

A.9.3 *Identification of the PIA and TAZs*

Demarcation of the PIA is vital for forming the TAZs. Major settlements and land uses along and in the influence area of the project corridor should be identified. A preliminary Origin and Destination (O-D) survey may also be carried out to understand the zones of influence of the vehicles (i.e. travel between O-D pairs) using the project corridor. This O-D survey is for identification of PIA and TAZs only. A more detailed O-D survey should be carried out in the later stages as described in **Section A.9.5**.

In forming the TAZs, care should be taken to identify the zones with distinct land-use pattern (viz. mines, quarry, industrial units, tourist spots, district headquarters etc.). The PIA should be divided into several TAZs, with proper road connectivity to the project corridor. Minor restructuring of TAZs may also become necessary after conducting the primary traffic surveys.

A.9.4 *Identification of the Homogenous Traffic Sections*

Homogenous traffic sections are the stretches of the project corridor where traffic volumes and/or composition are likely to be the same. Homogenous traffic sections should generally be identified based on the major points of diversion along the proposed project corridor (e.g. major intersections). The effect of the local traffic and travel pattern of the passenger and goods traffic should also be considered while identifying homogeneous sections.

A.9.5 *Identification of Primary Traffic Surveys and their Locations*

Primary traffic surveys are intended to understand the base year travel. These surveys include:

- Mid-block classified traffic volume count survey,
- Classified turning movement count survey at intersections,
- Origin-Destination, Occupancy and trip characteristics survey,
- Commodity survey,
- Travel behavior survey and
- Speed and Delay survey

For each identified homogenous section, at least one survey location should be selected for mid-block classified traffic volume counts. In order to have a reasonable estimate of the through traffic on the highway, it is necessary to select survey locations with negligible share of local traffic. It is generally done for 3 days or 7 days continuously. Turning movement count survey should be conducted at major intersections which may act as the major points of diversion for the traffic on the project corridor. It is generally carried out for 16 or 24 hours depending on the type of road section.

Origin-Destination and trip characteristics survey should be carried out on a sample basis along with the mid-block classified traffic volume count survey for a specified duration (generally 24 hours or 48 hours). On the road corridors where the traffic during night time is significant, the O-D survey should also cover night traffic. Trip characteristics data such as origin and destination of trip, trip frequency, purpose of the trip, etc. should also be collected.

Commodity survey should also be carried out through the O-D survey questionnaire on sample basis to understand the pattern of commodity movements on the project corridor.

Travel behavior survey may also be conducted at specific cases, such as toll roads or the project road where significant level of generated traffic are anticipated in horizon years. The survey is to be conducted through interviews of the road-users along the corridor, especially at dhabas, service centres, laybys, rest areas, parking areas, etc.

Travel time-delay surveys on the project corridor and the potential alternate routes would be helpful in assessing the diversion of traffic from/to the project highway, due to the improvement and also levying of toll on the project highway.

A.9.6 *Identification of the Secondary Data and their Sources*

Secondary data may consist of the following:

- Population
- Fuel-sales data along the project highway
- Agricultural and/or industrial output in the influence area of project highway
- Socio-economic data of the PIA, including economic parameters (Net District Domestic Product/Net State Domestic Product, Per capita Income) in the PIA.
- Past traffic data on proposed project corridor and/or surrounding road network
- Vehicle registration data (mode-wise/vehicle category wise)
- Land-use development plans viz. upcoming township, industrial unit/SEZ etc.
- Transport network/link development/improvement plan within the PIA.

Several other secondary data may be required for traffic forecasting and the secondary data requirements may also vary for different projects. The sources of various secondary data should also be identified and verified for authenticity and accuracy.

A.9.7 *Primary Traffic Surveys*

Primary traffic surveys are vital for collecting traffic data for the proposed project corridor operating under prevailing condition. The data collection shall meet the requirements as specified in A.9.5. This data shall provide the understanding of the base year travel demand/pattern on the project corridor.

A.9.8 *Collection of Secondary Data*

Based on the requirements of the project, the secondary data is required to be collected from different sources, which are normally the Census, State Economics and Statistics Department, Industries/Tourism/Ports Department, Regional Development Authority, State Planning Department, NHAI/MoRTH and State PWD, etc. The sources must be authentic and should be referred while preparing the final report on traffic forecast for the project corridor.

A.9.9 *Base Year Traffic Analysis*

In base year traffic analysis, the data collected from traffic surveys should be processed and representative ADT for each homogeneous traffic section should be estimated. If the computed/estimated ADTs on adjacent homogenous sections are similar, then the number of homogeneous sections may be reduced (by merging two or more homogeneous sections) with adequate justifications related to implications on capacity and design requirements. Generally traffic volume on highways or non-urban roads varies during different months or seasons in a year due to several factors. It is important to understand the reasons for such variations in the project context from local enquiries. Also, to account for such variations of traffic volumes during different months or seasons, it is necessary to estimate AADT from the measured ADT and secondary data reflecting seasonal variation.

A.9.10 *Estimation of Growth Factors for Normal Traffic*

This step includes estimation of traffic growth factors for projecting the normal traffic to horizon years. Normally, several approaches are adopted to compute and understand the growth rate of traffic on the proposed project corridor or in the PIA. These approaches include; i) Growth factors based on past traffic trend data on study corridor; ii) Growth factors based on past trends of vehicle population (registered motor vehicles) in the PIA; iii) Growth factors based on elasticity of transport demand; and (iv) Growth factors based on time series analysis. While estimating growth factors based on registered vehicle data, it should be kept in mind that the vehicle population may not be exactly equal to the number of registered motor vehicles as old vehicles are discarded as per the prevailing Government policies. Due to the unavailability of data, all the methods may not be suitable and applicable in all project contexts. Finally, the growth rates (factors) adopted for the horizon years should be by giving due and judicious consideration to realistic assessments of the past traffic growth, envisaged economic growth in the PIA, etc. The traffic engineer/planner may recommend growth rates, which are different from the growth trend observed in the past. However, the reasons for such recommendations are expected to be mentioned in the report.

A.9.11 *Horizon Year Transport Network*

The transport network for the PIA may be updated for different horizon years on the basis of the available information. This may be necessary to understand the likely change in the travel pattern, if any, and the effect on future traffic on the project corridor. The horizon year transport network is of critical importance in understanding the relevance and estimation of diverted traffic.

A.9.12 *Normal Traffic Forecast*

The normal traffic forecast at each horizon year is to be estimated by applying the recommended traffic growth rates/factors on the base year AADT.

A.9.13 *Developmental Traffic Forecast*

The estimation of developmental traffic, if relevant, should be carried out based on information obtained from local or regional development authorities. Developmental traffic should be estimated separately for each horizon year.

A.9.14 *Generated Traffic Forecast*

Generated traffic should be estimated separately for each horizon year. As generated traffic includes both diverted traffic and induced traffic, it is necessary to estimate these two components separately. If the generated traffic is ignored in the forecast of future traffic for the project corridor, necessary justifications should be provided for the same.

A.9.15 *Total Traffic Forecast*

Forecast of total traffic along the proposed project corridor at horizon years may be obtained by the compilation of the forecast of normal traffic, developmental traffic and generated traffic.

SECTION : B

METHODOLOGY

B.1 Analysis of Base Year Travel

Analysis of base year travel scenario involves conducting primary traffic surveys, collection of secondary data, and then analysis of all data to understand the base year travel and establish the base year traffic estimates for the project corridor.

B.1.1 *Primary Traffic Surveys*

Primary traffic surveys involve classified volume counts at selected mid-blocks and intersections along the project corridor and surrounding network, Origin-Destination of travel in PIA, type of commodity movements, etc. While carrying out classified vehicle counts, appropriate vehicle classification should be adopted as per relevant guidelines of IRC keeping in mind the presence of different vehicle categories operating on the project highway. The primary traffic surveys should be conducted as per the recommended procedures provided in IRC:SP:19-2001 "Manual for Survey, Investigation and Preparation of Road Projects" or its updated version. The equivalent Passenger Car Unit (PCU) values shall be used as per relevant IRC guidelines.

Mid-Block Classified Volume Counts

The midblock volume counts are representative of the through traffic on the project stretch and should be used for forecasting the future traffic volume on the project corridor. Therefore, it is recommended to carry out midblock traffic counts away from the intersections to avoid the effect of local traffic.

The classified volume counts should be carried out in both directions for successive 15 minute periods, for a minimum of 24 hours. Normally, for traffic forecasting on highways, it is necessary to carry out classified volume counts for a period of one week in order to account for the daily variation of demand which is predominant on such roads. There should be at least one survey location for each homogeneous traffic section as a control count station where classified volume counts should be carried out for one week. Depending on the length of the homogenous section and observed variation of traffic flows, additional classified volume counts may be carried out for shorter period (i.e. less than one week) at coverage count stations on project highway and on surrounding network. The average weekly traffic volume at each coverage station may be estimated using the survey data and the pattern of daily variation may be established.

Traffic volume surveys may be carried out using different methods such as manual count method (using paper-pencil or mechanical hand-counters), portable automatic count method (using pneumatic road tubes), permanent count station method (using loop detectors infrared system), satellite based system, video recording system, etc. Considering the cost of available technology and its suitability in mixed traffic operations with lack of lane discipline, manual count technique is acceptable in India for the purpose of traffic forecast. However, the practical constraints of suitable manpower required for the manual count method must be taken into account through proper design of field survey formats, training of enumerators, deployment of adequate number of enumerators and supervisors, etc.

As there is no scope of validation of data collected using manual method, it is desirable to record vehicular movements using videography and extract data using manual/semi-automatic methods. Other methods such as loop detector may also be used, if such methods have been established to produce reasonably accurate estimates under prevailing roadway, traffic and operating conditions.

Intersection Turning Movement Counts

The Intersection Turning Movement Counts are necessary to understand the traffic movements at intersections and also for design of intersections as per the local requirements. Apart from major intersections (which act as major points of diversion along the project highway), intersections having turning movements predominantly of the non-motorized vehicular modes and/or pedestrian movements (which substantially affect the operation of highway traffic during peak hours) should also be included in the primary traffic survey.

The intersection turning movement count survey should be carried out for successive 15 minute period, for a minimum of 24 hours on a working day. Turning vehicles from each approach of the intersection should be counted with classification of vehicles and recorded separately, as per respective turning direction of individual vehicle (viz. through movement, left and right turning movements).

Origin-Destination, Occupancy and Trip Characteristics Survey

The primary objective of the Origin-Destination and trip characteristics survey (normally termed as O-D survey) is to collect the travel related information for both the goods and passenger traffic moving on the project highway. O-D survey should be carried out along with the mid-block traffic volume count survey at specified locations for a minimum period of 24 hours. The survey may be carried out using roadside interview method. The vehicles should be intercepted on sample basis with the assistance of local police and trained enumerators should interview the drivers to obtain the required data. During the survey, the vehicle occupancy and information pertaining to origin and destination of the trip, duration of the trip, trip length and trip purpose as applicable for various vehicle modes should be collected and recorded. Sampling strategy and sample size for O-D survey should be justified.

Commodity Survey

Commodity surveys are to be carried out along with the O-D survey. The survey should focus on collecting information regarding the type and value of commodity (including the tonnage), carried by different category of goods vehicles such as local pick-up vehicles, 2-axle trucks, 3-axle trucks, multi axle vehicles, etc. moving along the corridor. The sample size for commodity survey should also be justified.

B.1.2 *Base Year Traffic Analysis*

Data collected through primary surveys and secondary sources are to be used for the base year traffic analysis. The various vehicle categories having different sizes and characteristics are to be converted into standard PCU value. PCU values may be taken as per IRC:64-1990 “Guidelines for Capacity of Roads in Rural Areas” or its updated version.

B.1.2.1 Average Daily Traffic (ADT)

Traffic volume count data for 7 days at each of the mid-block locations need to be averaged to determine Average Daily Traffic (ADT). The ADT should be expressed in PCUs using appropriate PCU values as per IRC: 64-1990 or its updated version. The peak hour and peak hour proportion of daily traffic should also be reported.

Composition of Traffic

The composition of traffic by vehicle category is to be worked out from the classified volume count data. The share of motorized and non-motorized traffic and the share of different vehicle categories such as bus, truck, LCV, etc. within the motorized traffic stream should be reported. A sample format for composition of traffic is shown in **Fig. B.1**. Suitable vehicle classification maybe adopted by the traffic engineer/planner depending on the project corridor and the context.

Station No.	Chainage (km)	Car & Jeep/Van	Three Wheeler	Two Wheeler	Mini Bus	Bus	LCV	Truck			Tractor	Tractor with Trailer	Non-Motorized Vehicles	Total
								2 Axle	3 Axle	Multi Axle				
1														100
2														100

Fig. B.1 Sample Format for Representing the Traffic Composition (in Percentage)

Hourly Variation of Traffic

The hourly variation of traffic volume should be reported and the observed pattern should also be explained. This may be computed using the ADT data, i.e. based on average daily traffic obtained from 7-day count data.

Daily Variation of Traffic

The daily variation of traffic should be studied and explained based on the 7-day count data.

A representative ADT should be indicated for each homogeneous traffic section. Vehicle composition, peak hour, hourly and daily variation of traffic should be reported for each survey station. Variation across different stations, if any, should be properly explained and accounted for. Also, any unusual pattern in terms of traffic volume and composition, etc. should be explained.

B.1.2.2 Rearrangement of homogeneous sections

Based on the representative ADT values, if it is observed that there is little or no variation (say, within 10%) in traffic volume and pattern for two or more consecutive homogeneous sections, they may be merged and considered as a single homogeneous traffic section.

B.1.2.3 Annual Average Daily Traffic (AADT)

Traffic volume on highways usually varies during different months or seasons in a year. Seasonal variation in traffic movement is expected mainly on account of variation in movement of agriculture produce and industrial products. The reasons for seasonal variation of traffic volume on a project stretch should be understood based on local queries and ground knowledge. Also, suitable secondary data to be collected to represent the variation of traffic volume during different seasons. Finally, the measured ADT should be converted into Annual Average Daily Traffic (AADT) using appropriate seasonal factors. Typically, a year may be split into three to four weather periods designated as seasons. But, the distribution of 12 months in a year to various seasons may depend on the geographic location of the project highway. Attempt should be made to derive separate seasonal factors for different vehicle categories, say, passenger and goods vehicles. Seasonal factors may be developed using secondary data such as monthly fuel sale data for at least three years, authentic vehicle category wise traffic data from any nearby toll plaza, or data from any permanent traffic count station in the area, etc.

B.1.2.4 Analysis of turning movement count data

The turning movement count data needs to be analyzed to represent daily traffic movement, share of non-motorized and motorized vehicles, peak periods, peak hour, peak hour proportion, etc. The result of the analysis should also be reported in the form of turning movement diagrams.

B.1.2.5 Analysis of O-D and commodity survey data

The sample O-D data collected from each survey station should be compiled for the base year, using the zoning system adopted for the study. Initially, the survey data may be compiled to develop vehicle category wise O-D matrices for one station. These O-D matrices then need to be expanded to develop O-D matrices for the population using appropriate expansion factors developed using the classified volume count data. Some of the zones may be combined at this stage if the contribution of those zones are found to be insignificant.

Occupancy

Passenger occupancy data collected during O-D surveys may be compiled to present the occupancy distribution and report the average occupancy value for each vehicle group.

Trip Purpose

The trip purpose information collected during O-D surveys (for passenger vehicles) may be compiled to represent distribution of trips by purpose.

Commodity Groups

The commodity data collected during primary surveys (along with O-D survey) should be analyzed and presented in suitable formats. Due consideration need to be given to include all possible commodities and to categorize them into homogeneous groups.

Load Analysis

The commodity data need to be used to understand the distribution of load carried by goods vehicles. The load carried by different categories of goods carrying vehicles viz. LCVs, two axle trucks, three axle trucks and multi axle vehicles are to be distributed in weight ranges.

Lead Analysis

The O-D survey data should be analyzed to obtain the average lead and lead ranges for various vehicle types. Different categories of vehicles viz. car, jeep, bus, mini bus, LCV, 2 axle truck, 3 axle truck, and multi axle vehicles shall be grouped and distributed on the basis of trip lengths or lead ranges.

B.2 Forecast of Travel Demand

The traffic forecast for each horizon year should be estimated considering three components: (i) normal traffic, (ii) generated traffic, and (iii) developmental traffic.

B.2.1 *Forecast of Normal Traffic*

Forecasting of normal traffic involves understanding the past traffic trend using different direct and indirect methods, which should be account for making realistic assessments of the traffic growth and envisaged economic growth in the PIA, which would allow estimation of AADT for horizon years.

B.2.1.1 Data requirements

The data requirements for estimation of growth rates are functions of the methods applied for estimating them. The following data should be compiled, when available and applicable for determining traffic growth rates:

a) Historical traffic count data (previous 5 to 10 years of traffic volumes)

b) Registered motor vehicle data in the zones of influence

c) Growth of different economic indicators in previous 5 to 10 years, such as population, per capita income, GDP, NSDP, NDDP, etc., in the PIA.

Based on the methodology adopted to determine growth rates, additional data such as fuel sales records, land use data/maps, etc. may also be required.

B.2.1.2 Establishing traffic growth trends

An understanding of the past traffic growth is necessary before establishing traffic growth rates for the horizon years. Different methods may be used to understand the past traffic growth and several approaches need to be explored to realistically assess and quantify the past traffic growth trends. Some of the approaches have been recommended in the following paragraphs. Other rational approaches may also be adopted with proper justification for analyzing the past traffic growth.

1. Growth factors based on past traffic data on study corridor

Plot historical ADT or AADT at a convenient scale with traffic volume on y-axis and year of count on x-axis.Use regression analysis combined with graphical representation for obtaining traffic growth trend. The graphical representation may show different growth rates for different periods within the available data, which may suggest appropriate considerations.

Attempts should be made to obtain growth factors separately for different vehicle categories. If data is not available at the required disaggregate level, then some of the vehicle categories may be combined logically to create lesser number of vehicle categories and obtain growth factor for each category separately. In situations where only the aggregate data (say, total PCU) is available, the growth factor may be obtained for the complete traffic stream. However, in this situation, it is necessary to derive growth factor according to vehicle category using other rational approaches. The overall growth of traffic obtained from different approaches can be used for comparison purpose.

It is worthwhile to mention that the past traffic data obtained from secondary sources may be inconsistent due to several reasons (such as presence of outliers). A few data points (showing extreme variation) may be excluded from the analysis to obtain rational trends in traffic growth. The inconsistency in the past traffic data obtained from secondary sources could be attributed to one or more of the following reasons:

a) **Inaccuracy of the data collected:** The traffic data is collected normally by manual method and there could be errors during collection of data and its processing. As the data has been collected manually, it is impossible to check the accuracy of that data at a later stage.

b) **Poor road conditions:** Till recently, not much attention was paid and very little resources were deployed for proper maintenance of highways. As a result, some roads may be experiencing very poor operating conditions. Poor road conditions severely affect the LOS and the maximum service volumes could be much lesser than the normal or that of similar road section under ideal condition. Such road conditions normally make the road less attractive for traffic movements and the vehicle volume data collected under such situations may not reflect the normal traffic level. In addition, the natural calamities, weather condition, ongoing road maintenance works etc. also may influence traffic volume on a corridor temporarily.

c) **Policy measures and other influences:** In practice, there could be an unexpected increase or decrease in traffic volumes due to number of policy measures. Several policies at the Government level such as change in cost of new vehicles, cost of fuel, taxes on several commodities etc. may influence traffic volumes. In fact, the fluctuating developing economy may result into a wide variety of situations, which may directly or indirectly affect the movement of traffic on a road.

It is because of all the aforesaid reasons, the past growth rates cannot be used directly for estimating future traffic on the project corridor. Any substantial change in policy (e.g., fare, travel time, loading and unloading of goods, etc.) and infrastructure (e.g. Improvement of existing rail services, new railway line, etc.) may also affect the traffic volume on the project corridor.

2. Growth factors based on registered vehicle data

The category wise registered motor vehicle data in each zone of PIA may be collected and analyzed to estimate growth factors. Plot historical registered motor vehicle data by vehicle category at a convenient scale with number of registered vehicles on y-axis and year of traffic count on x-axis. One can use regression analysis combined with graphical representation for obtaining growth factors for registered vehicles. It may also be possible that there is more than one trend in the period of data collected, which may be duly accounted in recommended growth rates.

For every vehicle category, the growth rate at different zones, along with the observed O-D pattern for the same vehicle category can be used to obtain the growth rate of that vehicle category for the travel in the particular O-D pair or group of O-D pairs. The basic assumption of this approach is that the growth of a vehicle category on a project highway is proportional to the growth of that vehicle category using the project road from the O-D zones of their travel in the influence area.

The traffic engineer/planner involved in the forecast needs to be careful that several state governments have their own policies to scrap old vehicles. In such cases, care should be taken to review the local/regional policies and consider the number of old vehicles that will be scrapped during the forecast period while adopting final growth rates.

3. Growth factors based on elasticity of transport demand

As the growth of vehicle population can also be related to other influences, an attempt may be made to relate vehicle population with one or more logically derived independent variables for deriving elasticity of transport demand. Elasticity of transport (traffic) demand, in the present context, is defined as the ratio of percentage change in traffic to the percentage change in socio-economic parameters. The concept of developing regression equation to relate the dependent variable in terms of one or more independent variable is widely used in transportation engineering for variety of purposes. The preferred dependent variable is past traffic on the project corridor. However, if the past traffic data is not consistent, number of registered motor vehicles in the zone of influence (Town/District/State) may be taken as dependent variable. The independent variables are socio-economic parameters. The choice of independent variables depends on vehicle type under consideration. It is logical to relate growth in traffic with NSDP/NDDP, PCI and population.

It is normally required to predict independently the socio-economic variables such as population, PCI, NSDP/NDDP, etc. for future years for assessing the future traffic growth rates using transport demand elasticity values. The traffic growth rates, by vehicle types, may be obtained by using simple regression and fitting the regression equation with prospective values of independent variables. The selection of variables and model is also a function of availability of data and model goodness of fit statistics (e.g. R^2, t-value, etc.).

4. Growth factors based on time series analysis

Wherever traffic volume data is available in time series (say, from an existing toll booth), the trend of traffic growth or the future traffic volume may be estimated using time series analysis. It comprises methods for analyzing time series data in order to extract meaningful statistics and other characteristics of the data. In special scenarios where past trends about independent variables affecting traffic growth such as population, PCI etc. are not available, time series analysis may be helpful for assessing future traffic volumes.

Time series analysis may be carried out using (a) Smoothening techniques, such as Single Moving Average (SMA), Double Moving Average (DMA), Single Exponential Smoothening (SES), etc., (b) Auto Regressive Moving Average (ARMA) Model, and (c) Auto Regressive Integrated Moving Average (ARIMA) model. If the data is limited, then ARMA or ARIMA model fit may not be good. In such cases time series based smoothening could be very effective.

It may be mentioned that in majority of projects involving four laning of existing two lane highways, it may not be possible to carry out time series analysis due to unavailability of data. In such cases, the growth rates should be investigated using other methods, as discussed above. On the contrary, where time series data are available from toll booths or from any other source, attempt should be made to make use of the available data, carry out time series analysis and compare the growth factor with those obtained from other methods.

B.2.1.3 Comparison of growth factors

Wherever possible, the growth rates estimated from different approaches should be compared in order to understand the degree of similarity or dissimilarity. Certain degrees of uncertainties are associated with growth rates obtained by each method and therefore the selection of growth rate plays a vital role in this regard. The analyst (traffic engineer/planner) may select one growth rate or an average of two or more growth rates by omitting the extreme results, or perform any other selection procedure. However, the selection of growth rates must be done with proper scientific justification.

B.2.1.4 Recommendation of future growth factors

The growth rates finally selected in **Section B.2.1.3** may be considered as realistic growth estimates of different categories of vehicles derived from the past trends. The knowledge of these growth rates is essential as a basis for suggesting future traffic growth rates for the project road. The traffic engineer/planner may modify the growth rates obtained from **Section B.2.1.3** considering the influencing factors and uncertainties, which may affect the future traffic levels on the project road and suggest future growth rates.

Normally, for a congested road (with high volume to capacity ratio) the traffic growth is expected to be lower. So, in most cases, lower growths may be reasonable till the capacity augmentation is done. Even after capacity augmentation, traffic growths are unlikely to be uniform during the entire design period. The growths are expected to be higher in the initial periods after road widening/improvement, and will become lower thereafter because of increasing traffic volume and reduced attractiveness of the road (i.e. more volume, less freedom of movement, more congestion, more travel time, etc.). Accordingly, separate sets of growth rates which are realistic for the context, may be evolved for obtaining traffic volume forecast for different horizon years.

B.2.1.5 Forecast AADT for horizon years

The AADT for different horizon years may be estimated using the base year AADT and recommended growth rates for each period.

B.2.2 *Estimation of Generated Traffic*

Estimation of generated traffic is a challenging task. Adequate investigations have not been carried out in Indian context to provide readily usable models or charts for the estimation of generated traffic. However, attempts should be made to estimate this component of future traffic volume in a realistic manner, especially for projects where the share of generated traffic is expected to be significant due to competing routes, modal shift, etc.

Several scientific techniques are available for the estimation of generated traffic. For the estimation of the two components of generated traffic (namely, diverted traffic and induced traffic), it is necessary to use behavioral data and suitable analysis technique to develop route choice and/or mode choice models. The broad steps involved in the development of mode choice or route choice model include, (i) design of travel behavior survey, (ii) collection of behavioral data, and (iii) analysis of the database by developing suitable econometric models. Two types of behavioral data may be necessary for such works namely Stated Preference (SP) data and Revealed Preference (RP) data. SP data are effective for valuation purpose or estimation of willingness-to-pay values, while use of RP data is desirable for demand estimation purpose. In some cases, it may be required to develop a joint RP-SP based model for demand estimation purpose. Different econometric modeling techniques may include Multinomial Logit (MNL), Nested Logit (NL) and Random Parameter Logit (RPL), etc.

Diverted traffic may also be projected using diversion curves. Diversion curves are empirically derived relationships for developing a logical estimate of the proportion of traffic that is likely to be diverted on the newly developed project corridor. The development of the diversion curve is based on the data collected from the road usage pattern in the past. The model may be based on the savings of travel time, savings of travel distance, travel time ratio, travel distance ratio, distance and speed ratio, travel cost ratio, toll rates, etc. Derivation of diversion curves should be based on alternative scenarios and variations in the above mentioned parameters for different vehicle categories. The established diversion curve may be used to calculate the diverted traffic for different categories of vehicle on the project corridor.

A different kind of analysis of SP data (other than Willingness-to-Pay survey) may be required in some contexts, where the primary effect is due to change in trip rate or vehicle-km travel. In such cases, Structural Equation Modelling (SEM) technique or any other established approach may be used. Any published work which may be relevant to the project context may also be referred and used as a basis for estimating the generated traffic with proper scientific justification. In cases where the generated traffic is anticipated to have very little or no significance, this step may be omitted for estimation of total traffic forecast for horizon years. However, such omissions should always be supported with proper justification.

B.2.3 *Estimation of Developmental Traffic*

In order to cater to the additional trips resulting from land use changes (like residential, commercial or industrial, etc.) in the influence area of the proposed road development, it is necessary to develop trip rate based projections for the horizon years. The trip rates may be obtained from secondary sources (say, previous studies which established trip rates for similar land use and comparable conditions) or established from primary surveys. The procedure may be similar to what is followed normally as a part of traffic impact studies. The output from this work is the additional daily traffic and peak hour traffic on the project road due to significant change in land use in the zones of influence. This component of traffic estimate may also be omitted with justification, if no significant development is expected in the zone of influence.

B.2.4 *Estimation of Forecast for Total Traffic*

The total traffic forecast for different horizon years should be obtained by combining the normal traffic forecast of AADT, the generated traffic and the developmental traffic volumes for each horizon year. The generated traffic and developmental traffic are case specific and may be omitted for some project corridors with proper justification.

B.2.5 *Impact of Toll on Travel Demand*

Quantifying the impact of toll on traffic volume forecast is again a complex but necessary task for toll roads. Toll is a negative externality (with deterrent effect) and may impact travel in several ways. First, it may result in a shift of route or mode of travel and thereby impacting the overall traffic volume on the project road. Secondly, the toll may also impact the trip rate or vehicle-km of travel. Therefore, methods as discussed in S**ection B.2.2** for the estimation of generated traffic may be used to develop model to estimate impacts of toll on traffic volumes. The amount of toll may be included as a part of direct cost while developing such models.

It may be noted that the impact of toll on travel demand of passenger and goods vehicles are expected to be distinctly different. Person trips (and thereby passenger vehicles) are expected to be more sensitive to toll. Therefore, it is meaningful to attempt to develop model and assess the impact of toll on passenger vehicles, as far as possible, in a rational manner. There may be limited scope for shift of mode (say, road to rail) for goods. The choice of route (say, use of local road instead of the project highway with toll) may also be restricted using policy and traffic management measures. All these aspects should be duly considered while assessing the impact of toll on passenger and goods traffic.

It may also be mentioned that there are added complexities associated with forecast of traffic on toll roads. As the concept of toll road is relatively new in India, there is little scope to analyze traffic growth on such roads based on observed data. It is therefore, necessary to update the forecast based on observed traffic volumes from time to time on the project corridor.

SECTION : C

APPLICATION

This section comprises of several example problems illustrating different methods that a traffic engineer/planner may adopt while carrying out traffic forecast. It may, however, be mentioned that the values and/or equations that have been used for solving the example problems are purely hypothetical. The traffic engineer/planner should develop realistic models and/or equations based on the project corridor for which forecast is being made.

C.1 AADT from ADT and Seasonal Variation

Problem Statement: The traffic volume data for a vehicle category say, two axle heavy commercial vehicles during different seasons are summarized in **Table C.1**. The observed ADT for the vehicle category in 2014 is 1482 and the traffic volumes are measured during June-July. Estimate the corresponding AADT in 2013.

Table C.1 Traffic Volume Data of Two Axle Heavy Commercial Vehicles (2T-HCV)

Year	Number of 2T-HCV During		
	Winter (Nov.-Feb)	Summer (Mar.-June)	Monsoon (July-Oct.)
2010	1389	1325	1480
2011	1600	1430	951
2012	1703	1362	1182
Average	1564	1372	1204
Seasonal Index	100	88	77

Solution: If the seasonal index for the peak season (i.e. winter as per the present example) is considered as 100, then the seasonal index for summer is 100*(1372/1564) or 87.72 and the seasonal index for monsoon is 100*(1204/1564) or 76.98.

The average seasonal index is (100*4+87.72*4+76.98*4)/12 = 88.23

The seasonal index during June-July may be considered as (87.72+76.98)/2 = 82.35

Therefore, the seasonal factor to convert the ADT counts during June-July to AADT is 88.23/82.35 or 1.07. Accordingly, the estimated AADT of 2T-HCV during 2014 is 1482*1.07 or 1586.

C.2 Traffic Growth Factor using Transport Demand Elasticity Model

Problem Statement: The time series data on Traffic Volume at a certain location and the corresponding data on GDP of the region are given in **Table C.2**. The GDP is expected to grow at a rate of 6 percent during 2005-2014. Determine the possible rate of growth of traffic during 2005-2014.

Table C.2 Time Series Data on Traffic Volume and GDP

Year	Traffic (PCUs/day)	GDP at constant Price (Rs. Crores)
2005	6,250	49,500
2006	6,550	51,200
2007	7,000	52,850
2008	7,250	54,275
2009	7,650	56,000
2010	8,000	57,500
2011	8,500	59,450
2012	8,850	61,000
2013	9,350	64,000
2014	9,900	65,300

Solution: The data in **Table C.2** is re-tabulated in **Table C.2A** to develop a linear regression model.

Table C.2A Table for Developing Linear Regression Model

Year	Traffic (P)	Ln P	GDP	Ln GDP
2005	10,000	9.21034	49,500	10.80973
2006	10,590	9.26767	51,200	10.84349
2007	11,210	9.32456	52,850	10.87521
2008	11,920	9.38597	54,275	10.90182
2009	12,640	9.44462	56,000	10.93311
2010	13,380	9.50152	57,500	10.95954
2011	14,200	9.56100	59,450	10.99289
2012	15,020	9.61714	61,000	11.01863
2013	15,980	9.67909	64,000	11.06664
2014	16,900	9.73507	65,300	11.08675

The data in columns representing Ln P and Ln GDP are now analyzed to develop a linear regression model which is as follows:

$$\text{Ln P} = -11.304 + 1.8976 \text{ Ln GDP}$$

The R^2 value (0.9977) of the regression model is high, the coefficients estimated (-32.2 and 59.2) are statistically significant at 95 percent confidence level and the signs of the coefficient estimated are logical. Therefore the model may be accepted.

The traffic demand elasticity coefficient is 1.8976. Therefore, if the growth of GDP is 6 percent for the year 2005-2014, then the estimated growth of traffic during the same period is 1.8976 x 6 percent or 11.39 percent as per the transport demand elasticity model.

C.3 Weighted Traffic Growth Rates using Growth Rates at Origin and Destination Zones

Problem Statement: The O-D survey on a National Highway reveals the following distributions of commercial vehicle movements: 30 percent between State-A and State-B, 20 percent between State-B and State-C, 25 percent between State-A and State-C and the rest 25 percent are distributed (in terms of both origin and destination) among other States in India. The growths of commercial vehicles are 7 percent, 6.0 percent, and 6.5 percent for State-A, State-B and State-C respectively. The growth of commercial vehicles at national level is estimated as 7.5 percent. What is the expected growth of commercial vehicles on the project highway?

Solution: For the vehicles moving between State-A and State-B, the growth of commercial vehicle is (7 percent + 6 percent)/2 or 6.5 percent.

Similarly, for vehicles moving between State-B and State-C, the growth of commercial vehicle is (6 percent + 6.5 percent)/2 or 6.25 percent. and between State-A and State-C, the growth of commercial vehicle is (7 percent + 6.5 percent)/2 or 6.75 percent.

The remaining States may be represented as a zone and the commercial vehicle growth of that zone may be assumed same as the national average i.e. 7.5 percent.

Therefore, the expected overall commercial traffic growth on the project highway is (30*6.5 + 20*6.25 + 25*6.75 + 25*7.5)/100 percent or 6.76 percent.

C.4 Growth Factor Estimation for Highways Passing through Urban Areas

Problem Statement: A section of the project corridor is passing through a dense urban area. Based on the nature and magnitude of traffic movement derived from O-D survey for the section of the project corridor, the shares of different types of traffic (in ADT and %) for urban, regional and through traffic are presented in **Table C.4**. Use appropriate analysis to obtain growth rate for the different types of traffic.

Table C.4 Different Types of Traffic Movement on the Project Road

Type of Traffic	Vehicle Volume (in ADT and %)					
	Cars	Bus	Two-Wheeler	2 Axle Heavy Commercial Vehicles (2T-HCV)	MAV	LCV
A	5768	476	4655	2540	343	2445
B1	2035	430	129	1609	508	894
B2	2165	830	133	1950	603	907
C	2670	1271	25	3317	1391	265
Total	12635	3007	4942	9416	2845	4511
A%	45.7	15.8	94.2	27	12.1	54.2
B1%	16.1	14.3	2.6	17.1	17.9	19.8
B2%	17.1	27.6	2.7	20.7	21.2	20.1
C%	21.1	32.3	0.5	35.2	48.8	5.9

Note to Symbols Used:

A: Zones 1-12 (Urban) (Internal - Internal), B1: Zones 1-12 to zones 13-20 (Regional) (Internal - External), B2: Zones 13-20 to Zones 1-12 (Regional) (External - Internal), C: Zones 13-20 (Through) to 13-20 (External - External)

Solution: For the purpose of traffic projections for different horizons years, it is necessary to develop relationship between traffic flow and other socio-economic variables. The data on vehicle registration can be considered to be useful in developing the econometric model.

For urban traffic, mode-wise vehicle registration data was regressed with various economic parameters and results are presented in table below. Only R^2 values along with 95 percent confidence limit are indicated as a part of goodness of fit in **Table C.4A**.

Table C.4A Results of Regression Analysis and Traffic Growth Rates for Urban Traffic

Vehicle Type	Electricity Value	R^2 Value	Exponential Growth of Population (%)-(P)	Per Capita Income Growth (%)-(R)	NSDP Growth (%)-(N)	Combined Rate Growth Factor (C)	Expression for Traffic Growth Rate	Traffic Growth Rate (%)
Cars	2.0	0.873	1.51	2.84	-	4.39	E*C	8.79
Bus	1.9	0.758	1.51	2.84	-	-	E*P	2.87
2-WH	2.9	0.923	1.51	2.84	-	4.39	E*C	12.74
Trucks	1.7	0.892	1.51	2.84	4.68	-	E*N	7.96

For regional traffic, the following parameters are used to estimate the growth factors. The results of elasticity of regional traffic are presented in **Table C.4B**.

Table C.4B Results of Regression Analysis and Traffic Growth Rates for Regional Traffic

Vehicle Type	Electricity Value	R^2 Value	Exponential Growth of Population (%)-(P)	Per Capita Income Growth (%)	NSDP Growth (%)-(N)	Combined Rate Growth Factor (C)	Expression for Traffic Growth Rate	Traffic Growth Rate (%)
Cars	2.9	0.943	2.12	2.58	-	4.39	E*C	12.74
Bus	1.6	0.887	2.12	2.58	-	4.39	E*C	7.03
2-WH	2.6	0.972	2.12	2.58	-	4.39	E*C	11.42
Truck	1.4	0.925	2.12	2.58	4.68	4.39	E*C	7.09

For through traffic, the GDP growth is taken into account to determine the growth of through traffic. The result of elasticity of through traffic is presented in **Table C.4C**.

Table C.4C Results of Regression Analysis and Traffic Growth Rates for Through Traffic

Vehicle Type	Electricity Value	R^2 Value	GDP Growth (G) (in %)	Expression for Traffic Growth Rate	Traffic Growth Rate (%)
Cars	1.6	0.98	5.45	E*G	8.72
Bus	0.97	0.745	5.45	E*G	5.29
Trucks	1.9	0.823	5.45	E*G	10.36

C.5 Updating Traffic Volume at Coverage Count Station Based on Data of Control Count Station

Problem Statement: A seven day 24-hr traffic volume studies were carried out at a control count station and the daily traffic volumes (in PCUs) from Monday to Sunday were measured as 21000, 23000, 23500, 24000, 20000, 18000 and 16000. The traffic volume at a coverage count station in the influence area of the control count station was measured as 14000 PCU based on a 24 hour volume survey on Thursday of the same week. Calculate the adjusted ADT (i.e. weekly average) for the coverage count station.

Solution: The weekly average daily traffic volume at the control station is 20786 PCU.

The weekly average is 20786/24000 or 0.866 times the daily traffic on Thursday. As the traffic pattern at the coverage count station is assumed to be similar to that of the control count station, the adjusted ADT for the coverage count station (i.e. average of weekly count) is estimated as 14000*0.866 or 12124 PCUs.

C.6 Traffic Forecasting using Moving Average Technique and Single Exponential Smoothening Technique

Problem Statement: The Observed Monthly ADT (MADT) of commercial vehicles for consecutive 19 months on a toll booth is provided in column 2 of **Table C.6**.

a) Calculate a three month moving average for months one to nineteen. What would be the forecast for the commercial vehicle on that toll booth in 20th month?

b) Apply exponential smoothing to forecast the volume of commercial vehicles in the twentieth month.

c) Which of these two forecast techniques should be preferred in practice and why? Give proper justification

Solution:

a) There are different moving average techniques used for forecasting purpose, such as two-month, three-month, four-month average and so on. In this case, three-month moving average technique is used for the analysis.

The three-month moving average MADT for Month-3 is calculated as (852+861+958)/3 or 890. In the similar manner, the values are calculated for other months and reported in column 3 of **Table C.6**. The forecast for month 20 is just the moving average for the month before that i.e. the moving average for month 19 = 1286.

b) Single Exponential Smoothening Technique follows the following formula to smoothen the dataset.

$$S_t = \alpha y_t + (1-\alpha)S_{(t-1)}$$

Where,

S_t is the predicted smoothened data point, y_t is the observed data point, $S_{(t-1)}$ is the previous smoothened data point and α is the smoothening factor. The value of α ranges from 0 to 1 and may be selected by minimizing the SSE (Sum of squared errors) over the period for which y_t is known (in the given example, that period is 19 months). For the purpose of this example, the value of α is considered as 0.1.

The single exponential smoothened MADT for Month-3 is calculated as (0.1*861) + (0.9*852) or 853. In the similar manner, the values are calculated for other months and reported in column 4 of **Table C.6**. The forecast for month 20 is just the single exponential smoothened MADT for Month-19 = 1237.

c) To compare the two forecasts, the Mean Squared Deviation (MSD) is calculated.

For the moving average technique,

$MSD_{\text{Moving Average}} = [(890-1037)^2 + (952-1045)^2 ..... + (1225-1349)^2]/16 = 16225$

$MSD_{\text{Single Exponential Smoothening}} = [(852-958)^2 + (853-1037)^2 ..... + (1174-1349)^2]/17 = 27739.$

Overall it can be concluded that the three-month moving average appears to give a better one-month ahead forecast as it has a lower MSD. Hence, the forecast of 1286 will be considered as the Monthly ADT in terms of commercial vehicle in that toll booth in the twentieth month.

Table C.6 Example of Moving Average and Single Exponential Smoothening

Month	Original MADT	Moving Average MADT	Forecast MADT (Moving Average)	Single Exponential Smoothened MADT	Forecast MADT (Single Exponential Smoothened)
Month-1	852				
Month-2	861			852	
Month-3	958	890		853	852
Month-4	1037	952	890	871	853
Month-5	1045	1013	952	966	871
Month-6	1109	1064	1013	1038	966
Month-7	1117	1090	1064	1051	1038
Month-8	1134	1120	1090	1110	1051
Month-9	1236	1162	1120	1119	1110
Month-10	1077	1149	1162	1144	1119
Month-11	868	1060	1149	1220	1144
Month-12	997	981	1060	1056	1220
Month-13	962	942	981	881	1056
Month-14	907	955	942	994	881
Month-15	1098	989	955	957	994
Month-16	1167	1057	989	926	957
Month-17	1232	1166	1057	1105	926
Month-18	1277	1225	1166	1174	1105
Month-19	1349	1286	1225	1237	1174
Month-20			1286		1237

C.7 Application of ARIMA Model for Forecasting Future Traffic Growth Rate

Problem Statement: The growth rate of two wheelers in a medium-sized Indian city for the past 34 years (1979-2012) is collected and tabulated in **Table C.7A**. Predict the future growth rates of two-wheelers in the city for another 15 years (2013-2028) using ARIMA model.

Table C.7A Two Wheeler Growth Rates (1979 - 2012)

Year	2W Growth Rate (in %)	Year	2W Growth Rate (in %)	Year	2W Growth Rate (in %)	Year	2W Growth Rate (in %)	Year	2W Growth Rate (in %)	Year	2W Growth Rate (in %)
1979	3.65	1985	4.36	1991	4.65	1997	5.85	2003	7.38	2009	8.16
1980	3.73	1986	4.34	1992	4.81	1998	6.06	2004	7.34	2010	8.38
1981	3.93	1987	4.31	1993	5.02	1999	6.14	2005	7.65	2011	7.92
1982	4.02	1988	4.38	1994	5.27	2000	6.48	2006	7.77	2012	8.07
1983	3.86	1989	4.39	1995	5.53	2001	6.79	2007	7.96		
1984	4.12	1990	4.43	1996	5.62	2002	7.22	2008	8.18		

Solution: The model is generally referred to as an ARIMA (p,d,q) model where p, d and q are non-negative integers that refer to the order of the auto regressive, integrated and moving average parts of the model respectively. Here, using ARIMA model, the growth of vehicles for future forecast is provided and step wise procedure is briefly demonstrated.

Model Identification: To fit an ARIMA model of dataset, it is necessary to find out whether dataset is time series data and also if it is univariate or multivariate. To observe time series trends, the dataset is plotted according to time. Then ACF and PACF parameters are estimated to define the order of series. The ACF plots represent Auto Correlation and PACF plots represent Partial Auto Correlation of data sets against lags of themselves. In this given problem based on ACF and PACF plot of an ARIMA (1, 1, 0) model has been applied on the case dataset for the future prediction which is presented in **Fig. C.7**.

Diagnostic Checking of the Model: Ljung-Box test is used for examining the null hypothesis of independence in a given time series. The model statistic shows that the p-value for the Ljung–Box test is 0.822, well above 0.05, indicating "non-significance" and this can be taken as desirable result.

Prediction of ARIMA–Models: Once a model has been identified and found statistically significant, future values can be estimated using the model. The growth rates of two wheelers are estimated up to 2028 using the specified ARIMA model and the future trend is shown graphically in **Fig. C.7**. The forecast growth rate along with the observed growth rate is reported in **Table C.7B**, shows a less steeper but increasing trend of growth rate for two-wheelers in the city up to 2028.

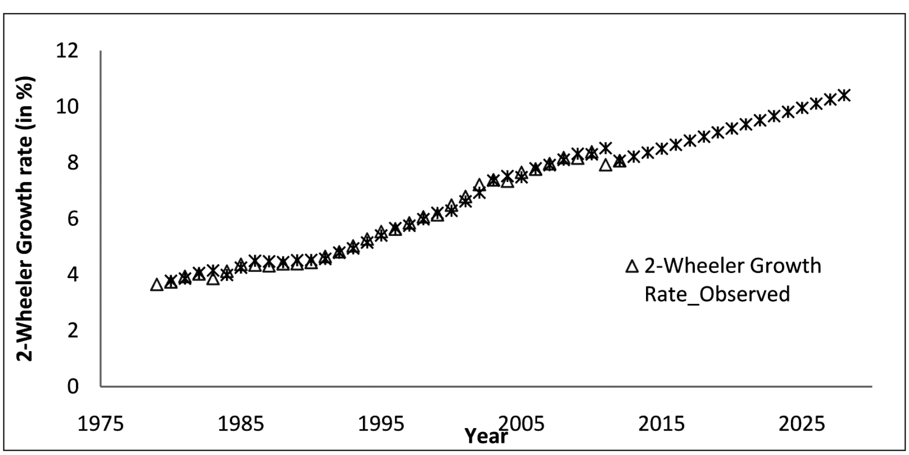

Fig. C.7 Observed Growth Rate and Forecast for Two-Wheelers

Table C.7B Forecast of Two-Wheeler Growth Rate (in %)

Year	2-Wheeler Growth Rate Observed (in %)	2-Wheeler Growth Rate Forecast with ARIMA (in %)	Year	2-Wheeler Growth Rate Observed (in %)	2-Wheeler Growth Rate Forecast with ARIMA (in %)	Year	2-Wheeler Growth Rate Forecast with ARIMA (in %)
1979	3.65		1996	5.62	5.66	2013	8.21
1980	3.73	3.78	1997	5.85	5.75	2014	8.36
1981	3.93	3.86	1998	6.06	5.98	2015	8.5
1982	4.02	4.06	1999	6.13	6.2	2016	8.64
1983	3.86	4.15	2000	6.48	6.28	2017	8.79
1984	4.12	3.99	2001	6.79	6.62	2018	8.93
1985	4.36	4.25	2002	7.22	6.93	2019	9.08
1986	4.34	4.49	2003	7.38	7.36	2020	9.22
1987	4.31	4.47	2004	7.34	7.52	2021	9.37
1988	4.38	4.44	2005	7.65	7.48	2022	9.51
1989	4.39	4.51	2006	7.77	7.79	2023	9.66
1990	4.43	4.52	2007	7.96	7.91	2024	9.81
1991	4.65	4.56	2008	8.18	8.1	2025	9.96
1992	4.81	4.78	2009	8.16	8.32	2026	10.11
1993	5.02	4.94	2010	8.38	8.3	2027	10.26
1994	5.27	5.15	2011	7.92	8.52	2028	10.41
1995	5.53	5.4	2012	8.07	8.06		

C.8 Estimation of Diverted Traffic using Logit Model

Problem Statement: An existing road connects two cities A and B. The length of existing route is 12 km. A new highway is planned to connect the two cities. The length of the new highway alignment is 18 km. During peak hour, Travel Time (TT) and Travel Vost (TC) along the existing route are 25 minutes and Rs.4 per kilometer respectively. For the new highway facility, TT and TC during peak hour has been estimated as 15 minutes and Rs.3.5 per kilometer respectively. Based on travel behavior studies, a utility function has been developed to estimate the shift of passenger car from the existing route to the proposed highway as U = -0.21* TT - 0.178*TC - 0.464. Alternative specific constant for existing highway is -0.464. Observed peak hour traffic volume of passenger cars along the existing route is 4000. Estimate the shift of passenger cars to the proposed highway during the peak hour.

Solution: Using the given utility function,

Utility of the existing route, U_1 = -0.21* 25 - 0.178*4*12 – 0.464 = -14.258

Utility of the proposed route, U_2 = -0.21* 15 - 0.178*3.5*18 = - 14.364

Hence, the percentage shift of passenger car to the proposed route as per bi-nomial logit model

= $\exp(U_2)/\{\exp(U_1) + \exp(U_2)\}*100$ = 47.35%

Therefore, the estimated shift of passenger car to the proposed highway during peak hour

= 4000*47.35% = 1894 cars

C.9 Estimation of Diverted Traffic using Diversion Curves

Problem Statement: A new Expressway is proposed to be developed which will act as a competing route to an already existing National Highway. Classified volume count on the existing National Highway is 1500 cars/hour, 100 buses/hour and 400 trucks/hour. Use the diversion curves provided in **Table C.9** to estimate vehicle category wise diverted traffic to the newly developed Expressway. The Travel Cost Ratio (Expressway : National Highway) for cars, buses and trucks have been estimated as 0.816, 0.913 and 0.776 respectively.

Table C.9 Diversion Curve Equations

Item	Cost Ratio Interval	Equations
Cars	< 0.634	% Div = 98.750 - (CR/0.634)*8.125
	0.634 < = CR < = 1.465	% Div = 90.625 - ((CR-0.634)/0.831)*84.375
	1.465 < = CR < = 2.00	% Div = 06.250 - (CR-1.465)/0.535)*5.25
Buses & Trucks	< = 0.750	% Div = 100-(CR/0.75)*0.5
	0.750 < = CR < = 1.250	% Div = 95 - ((CR-0.75)/0.5)*90
	1.250 < = CR < = 2.00	% Div = ((2-CR)/0.75)*5

Source: Project Report on Indian National Expressway Network, MORTH (2009)

Solution: The Percentage Diversion of Cars, Buses and Trucks are as follows:

Cars (CR = 0.816) % Div = 90.625-((0.816-0.634)/0.831)*84.375 = 72.15%

Buses (CR = 0.913) % Div = 95-((CR-0.75)/0.5)*90 = 65.66%

Trucks (CR = 0.776) % Div = 95-((CR-0.75)/0.5)*90 = 90.32%

Therefore, the mode-wise diverted traffic to the newly developed Expressway is as follows:

Cars: 72.15% * 1500 = 1082 Cars/hour

Buses: 65.66% * 100 = 66 Buses/hour

Trucks: 90.32% * 400 = 361 Trucks/hour