MODELLING TRIP GENERATION RATES FOR INDIAN CITIES

submitted in partial fulfillment of the requirements

for the award of the degree of

Doctor of Philosophy

by

Villuri Mahalakshmi Naidu

701130

Department of Civil Engineering

NATIONAL INSTITUTE OF TECHNOLOGY

WARANGAL

August-2019

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Approval Sheet

This Thesis entitled **"Modelling Trip Generation Rates For Indian Cities"** by **Mr. Villuri Mahalakshmi Naidu** is approved for the degree of **Doctor of Philosophy**.

Examiners

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Declaration

This is to certify that the work presented in the thesis entitled **Modelling Trip Generation Rates For Indian Cities** is a bonafide work done by me under the supervision of **Prof. C.S.R.K Prasad** and **Dr. Manchikanti Srinivas** and was not submitted elsewhere for the award of any degree.

I declare that this written submission represents my ideas in my own words and where others' ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea / data / fact / source in my submission. I understand that any violation of the above will be a cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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(Signature)

V. Mahalakshmi Naidu

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Date: __________

NATIONAL INSTITUTE OF TECHNOLOGY WARANGAL

Certificate

This is to certify that the thesis entitled **"Modelling Trip Generation Rates For Indian Cities"** submitted by **Mr. Villuri Mahalakshmi Naidu** to the National Institute of Technology, Warangal, for the award of the degree of **Doctor of Philosophy in Civil Engineering** is a bonafide research work carried out by him under our supervision and guidance. The results contained in this thesis have not been submitted in part or full to any other University or Institute for award of any degree or diploma.

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Dedicated to

My
Beloved Family
&
Gurus

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ABSTRACT

In this modern world where everything is becoming smart, there is a great need for the trip forecasting to catch up with the transportation planning. Cities across the world are growing in terms of their urban area and in number. Every city has its travel demand based on its socio-economic and land use characteristics. Number of trips generated in a day per person in a city is considered as Trip Rate. **In this work, trip generation rate, Per Capita Trip Rate are synonymous with the word Trip Rate**.

Present transportation planning models are prepared for estimation of cross-sectional data, hence are referred to as cross-sectional demand models. These works have demonstrated the theoretical and practical significance of developing travel demand models based on panel data (Kitamura 1988; Kitamura 1990; Meurs 1990; Goodwin et al. 1987; Michael et al. 2002 and 2006). Residential trip rates are underreported by the residents, especially trips that are not made with consistency. Retail trips are probably underreported than trips for work purpose (Reid 1982; Kumar et al. 1993). Modelling of small urban regions using single internal trip purpose was carried out by Anderson (2001).

Yam et al. (2000) formulated a multi linear regression model to assess traffic generation to high density, large scale, multi-story public residential accommodation estates in Hong Kong. The cross-classification analysis is more universally adopted (McNally 2000) with applications in passenger travel (Guevara et al. 2007) and also freight (Bastida et al. 2009). Even though, there were various attempts in the field of trip generation, quick estimates of trip generation rates for developing countries has become a field of rare focus. Keeping this in view, trip generation rate estimation process is studied for a developing country like India.
Trip generation studies include Cross-classification, Linear Regression, count data and neural network techniques. However, there is requirement for advancement in this matter. Instant estimation of trip generation rates for developing countries is required. Hence, this research work is taken up.

Parameters related to socio-economic status and land use were considered in the study. It is found that trip rate varies with power function, trip length varies linearly with respect to population of the city. Both these parameters vary exponentially with population density. For combined data, City Population and Industrial Area (%) are found to be having a logical sign,

and population parameter is found to be most significant in the trip rate model. Cities were categorized based on population and area. Cities are categorized based on the population as CP1 (Population <10 Lakhs), CP2 (Population: 10-40 Lakhs) and CP3 (Population >40 Lakhs). Cities are categorized based on the Area as CA1 (Area <300 sq.km), CA2 (Area: 300-1000 sq.km) and CA3 (Area >1000 sq.km). Regression models were developed for these categories. Regression models were developed for combined cities and categorized cities data. As multiple parameters are available, the Principal Component Analysis (PCA) is used to reduce the dimensionality. Combined data (Socio-economic and Land-Use) is processed to get principal components. Better regression models were developed for the data of all the cities with principal components.

Data was processed through Artificial Neural Network (ANN) for trip rate prediction. For accurate prediction of trip rate, ANN has been applied. The Artificial neural network analysis with same data (Socio-economic and Land-Use) was employed. Performance of these models using ANN is found to be better than the performance of corresponding regression models. Various sets of Nomograms were developed to assess the trip rate using different input variables for all the city categories considered. PyNomo, sub-module of Python program was used for developing Nomograms. For all categories of cities, various Nomograms were developed with single and two input variables.

Trip rate increase with population size and this increase is steep up to a population of 40 lakhs. There is an abrupt change around 40 lakhs and increase in trip rate is found to be nominal, beyond 40 lakh population. The trip length of the city increases with the increase in population size. Regression analysis revealed that city population is found to be the significant variable in explaining Trip Rate. The training function TRAINLM has performed perfectly using the Feed Forward Back Propagation algorithm producing a predicted trip rate value. Principal Components with Artificial Neural Network arrangement models yielded superior correlation coefficient.

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LIST OF ABBREVIATIONS

ANN	-	Artificial Neural Network
CAGR	-	Compound Annual Growth Rate
CA1	-	City Area 1 (Area < 300 sq.km)
CA2	-	City Area 2 (300 <= Area <= 1000 sq.km)
CA3	-	City Area 3 (Area > 1000 sq.km)
CP1	-	City Population 1 (Population < 10 lakhs)
CP2	-	City Population 2 (10 lakhs <= Population <= 40 lakhs)
CP3	-	City Population 3 (Population > 40 lakhs)
CTS	-	Comprehensive Transportation Study
CDP	-	City Development Plan
CMP	-	Comprehensive Mobility Plan
ITE	-	Institute of Transportation Engineers
km	-	Kilometer
MCA	-	Multiple Classification Analysis
MSE	-	Mean Square Error
MLR	-	Multiple Linear Regression
MXD	-	Mixed-use Development
Nos	-	Numbers
PCA	-	Principal Component Analysis
PCTR	-	Per Capita Trip Rate
Rs.	-	Indian Rupees
sqkm	-	Square Kilometers
TAZ	-	Traffic Analysis Zone
R	-	Coefficient of correlation
PC	-	Principal Component
pdf	-	Portable Document Format
EPS	-	Encapsulated Post Script

Chapter1

Introduction

1.1. Urbanisation and Vehicular Growth

In India, population in urban areas has increased significantly from 62 million in 1951 to 377 million in 2011 and is estimated to be around 540 million by the year 2021. With respect to total population, the urban population has increased from 17% in 1951 to 31% in 2011 and is likely to increase up to around 37% by the year 2021 (Source: http://ayush.gov.in). Population growth largely influences the total number of vehicles in the nation. If a population growth was the only critical factor, the number of motor vehicles would grow at the identical rate as residents. Number of motor vehicles depends upon population, income, number of employees etc. India has witnessed tremendous growth in the number of motor vehicles in the last few years as shown in Figure. 1.1. Some analysts predicted that India's motorization rate would be expected to increase to 40 vehicles per 1000 Persons by 2020.

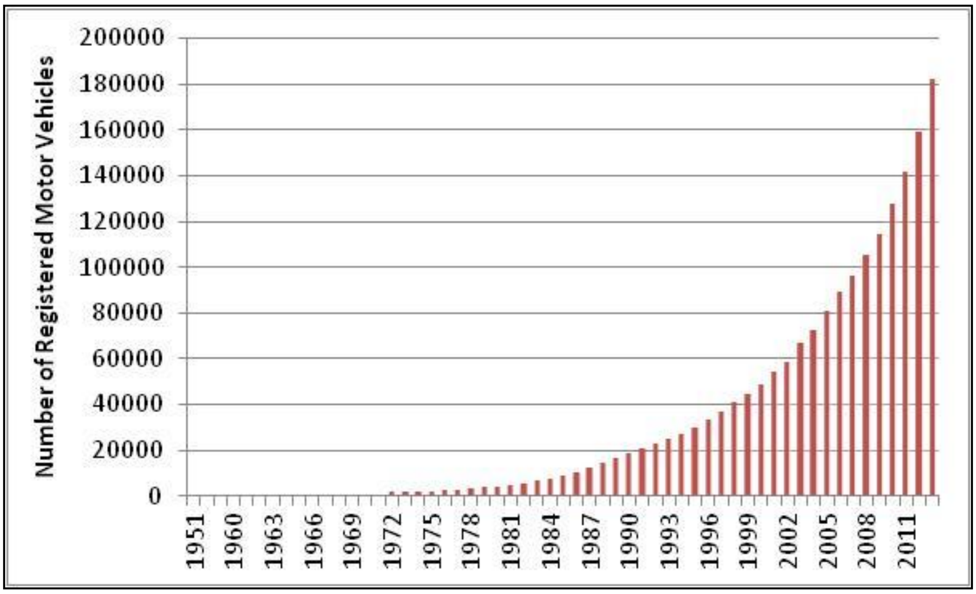


Figure 1.1: Total Motor Vehicles Growth in India (Source: www.data.gov.in)

The majority of the vehicles in India are found to be in metro cities. Number of vehicles in Indian cities is 40 million with a share of 30 % of total vehicles in India. Chennai, Bangalore, Kolkata, Delhi, and Mumbai with 15.2 million vehicles constitute 38 % of a total number of the vehicles of the main cities in India and 13 % of total vehicles in India.

The second tier cities like Coimbatore (12%), Madurai (11%), Nagpur (14.6%) and Vishakhapatnam (17.2%) had already posted a compound annual growth rate (CAGR) of about 11% or more. Mumbai and Chennai posted a growth rate of 6.2% and 13.2% respectively (Source: www.data.gov.in).

1.2. Travel Demand

Modelling of travel demand is to create the geographical distribution of travel explicitly through a proper system of zones. Demand modelling is a procedure for finding out what travel decisions people would like to build given the generalized travel cost of various travel options. The main decisions include the destination choice, mode choice, and the route choice. Even though different modelling methods are implemented, the classical transport four-stage model is very popular. The flow form of the four-stage travel demand modelling is given in Figure 1.2 (Mathew, 2009).

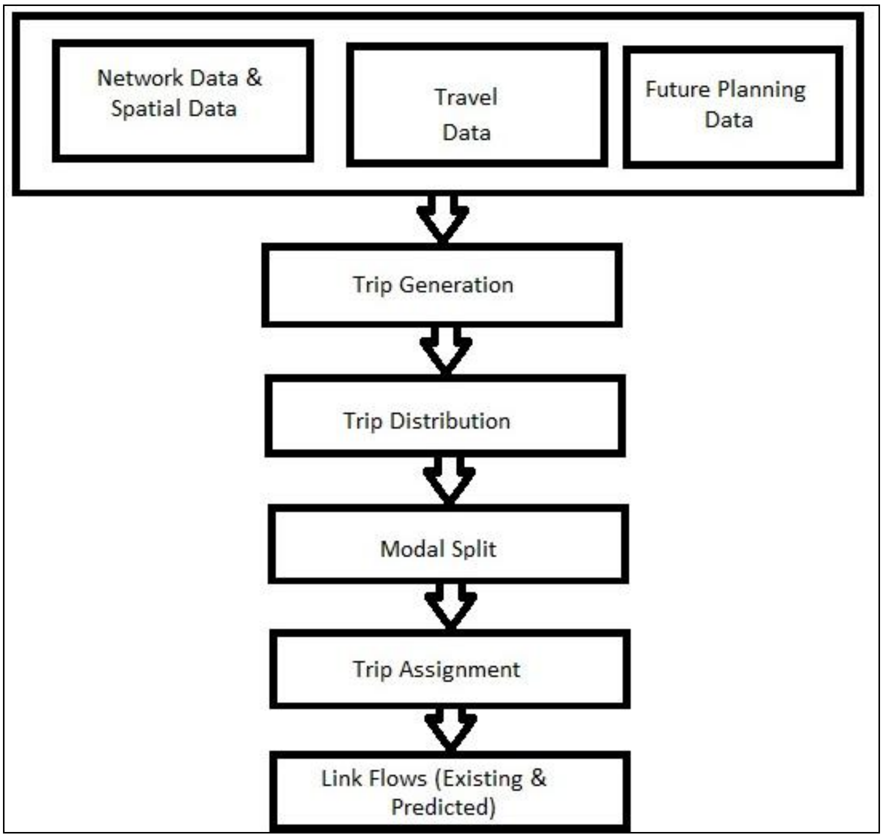


Figure 1.2: Flow of Four Stage Transport Planning Process

This model is presented as a series of four sub-models: trip generation, trip distribution, modal split and trip assignment. The models begin with defining the study area and separating them into the number of zones and considering the road network in the study area. The data list also includes the present levels of population, educational, economic activity like employment, shopping centers, and facilities of each zone. Then, trip generation model is developed which uses the database to predict the total number of trips generated and attracted from every zone. The next step is the distribution of these trips from every zone to various other destination zones in the study area with the help of trip distribution models. The output of the trip distribution model is a trip matrix which denotes the trips from every zone to every other zone. In the subsequent step, the trips are allocated to various modes based on the modal characteristics using various methods. It essentially divides the trip matrix for various modes generated to a trip matrix with a particular mode (Wilson et. al., 1971). And, each trip matrix is assigned to the network of that mode using the trip assignment models. The trip assignment step will give the traffic flow on each link of the network.

Sequential aggregate models are worked based on aggregate behaviour of zones. The modelling process will be in a particular order. Output of one step is an input to subsequent step. This model predicts the travel demand in series of independent steps. **Direct aggregate models** develop all the attributes in one single equation but still based on aggregate travel behaviour. **Sequential disaggregate behavioural models** focus on the behaviour of the smallest decision making unit, namely the individual trip maker. It is understood that the probability of making a given choice is based on behavioural pattern of individual traveller. **Direct disaggregate models** incorporate the behaviour of individual structure of all the travel decisions as a simultaneous of all the travel decisions and direct process rather than sequential (Kassoff et. al., 1969). **Activity-based travel demand models** (Bhat et. al., 1999) are established on the rule that travel demand is initiated from people's daily activity patterns. Activity-based travel demand models foresee which activities are conducted when, where, for how long, for and with whom, and the travel choices they will make to complete them.

In the field of activity generation, Poisson model was used (Ma et al. 1999). Frequency of shopping activities at household level through count data model was focussed (Bhat et al. 1998). A multi linear regression model to assess traffic generation to high density, large scale, multi-story public residential accommodation estates in Hong Kong was formulated (Yam et al. 2000). Models were prepared for the trip generation at city level using either multiple linear regression analysis or cross-classification/category analysis. The cross-classification analysis is worked (McNally, 2000) with relevance in passenger travel (Guevara et al. 2007) and also freight (Bastida et al. 2009). These approaches are explained in different papers (Meyer et al. 2000, Ortuzar 2001). Multiple classification analysis (MCA) is planned as an additional technique for focussing on the troubles of cross-classification analysis (Stopher et al. 1983, Breiman et al. 1984).

1.3. Estimation of Trip Generation Rates

Trip generation rates are estimated based on travel surveys. The travel surveys include Household interview survey and Traffic count for calculation of trip rates. To estimate per capita trip rate for various cities, household interview survey data will be used (A Report on Traffic and Transportation Policies and Strategies for Urban Areas, 2008). And, for trip rate calculation of various land uses, traffic count survey data will be utilized (Guide to Traffic Impact Assessment, Transport and Main Roads, Queensland, Australia, September 2017). In this work, trip generation rate, Per Capita Trip Rate are synonymous with the word Trip Rate. Number of trips generated in a day per person in a city is considered as Trip Rate. Motorized Trip Rate is Trips per day per person (other than walk, bicycle etc.) in a city.

1.4. Problem Statement

For bigger cities, transportation planning is required to plan the facilities. To achieve travel demand assessment for any city using conventional four-step demand modelling, it would require a lot of time, and also resources. Especially for medium and small cities, quick estimates are required for the road network and node improvement. So, there is an indispensable need for the study of trip rates concerning various socio-economic and land use variables. Several countries have developed various manuals on trip generation especially the Institute of Transportation Engineers in America (Trip Generation Manual, 9th Edition, 2012), South Africa Committee of Transport Officials (South African Trip Data Manual in 2013). Department of Planning (Report on Trip Generation rates for assessment of development proposals, 2014) discussed on trip generation rates of New Zealand, Australia, and the UK. But, India lacks sufficient work on these trip generation rates.

As of now, to appreciate the travel demand for specific city using existing parameters, there are no competent models for developing countries. Given this, an effort has been made in this thesis to model the travel prediction with the help of readily obtainable parameters. Various methods have been discussed using various socio-economic parameters and land-use parameters for prediction of trip rate. An effort has made to give quick estimates of trip rates for any given city with easily available parameters.

1.5. Objectives of the Study

After broad assessment of various transportation planning aspects and a comprehensive study of related literature and with a broad idea to develop a simplified methodology using novel methods, the present research work was taken up with the following objectives:

1. To investigate and develop per capita trip rates for Indian cities
2. To assess the impact of Principal Component Analysis on trip rate estimation
3. To explore the applicability and develop models using soft computing technique for trip rate prediction
4. To develop Nomograms for trip rate prediction

1.6. Thesis Structure

This thesis report is organized into seven chapters as indicated below.

The first chapter presents *"Introduction."* The general description of Urbanisation and vehicular growth, travel demand, Estimation of trip generation rate, problem statement, and motivation for carrying out research in the area of "Modelling Trip Generation Rate for Indian Cities" is presented. The objectives of the thesis are also outlined.

The second chapter presents *"Literature Review."* The review of literature in the selected area is discussed. In this chapter, critical review, comparative statement of various methods, Gaps in the existing work and scope of present work is also discussed.

The third chapter discusses *"Study Methodology."* This chapter focuses on general discussion of study process, sequence of activities in the form of a flow chart.

The fourth chapter focuses on *"Study Area and Preliminary Data Analysis."* This chapter focuses on the study area, data collection, and preliminary analysis findings.

The fifth chapter displays "*Trip Rate Prediction Models*." In this chapter, the trip rate interaction with land use and socio-economic parameters using linear regression, regression models with Principal Components are discussed. Processing of socio-economic data and land use data jointly to the neural network is discussed. Results of Principal components (formed by the socio-economic and land use parameters) input to the neural network is also discussed.

The sixth chapter presents "*Nomograms to Assess Trip Rates*". In this chapter, methodology to create Nomograms is discussed, including Nomograms for population and city area categories.

The seventh chapter presents "*Summary and Conclusions*." In this chapter summary, conclusions, limitations, and scope for further study are discussed.

Chapter 2
Literature Review

2.1. General

In continuation with the chapter on introduction, which includes need of travel demand, objectives of the study and thesis organisation, in this chapter, literature review on trip generation under various groups of Cross-classification, Regression analysis, count data, ANN models and scope of the work will be discussed.

2.2. Trip Generation Rate Analysis

Trip generation is the first stage of the four stage transportation planning process. The purpose of the trip generation stage is to appreciate the causes behind the trip making behaviour and to develop statistical relationship to combine the trip making pattern on the basis of surveyed trips, land use data, household features and trip attraction is the trip made to specific activity centres. Techniques used for Trip Generation are as follows:

1. Cross-Classification / Category Analysis
2. Regression Analysis
3. Trip Generation based on Panel and Count data
4. Models based on Neural Networks

The three key techniques used for Trip Generation Analysis are Cross-Classification, Multiple Regression Analysis, and Experience Based Analysis (Trip Generation Manual, 2012). Institute of Transportation Engineers has developed Trip Generation Manual (2012) and it is one of the best sources of generalized trip generation rates. To get community trustworthiness, a survey of alike land uses in the area may also required to be organised.

Various trip generation techniques and studies are given below.

2.2.1. Cross-Classification / Category Analysis

Category analysis is a practice derived from the unit of the household and its qualities. Cross-Classification method computes the variations in one parameter (trips) when other parameters (land use etc.) are accounted for. Cross-Classification is similar to multiple regression techniques. This method is basically non-parametric, since no account is taken of the allocation of the different values. Major drawback with this technique is that the "independent" variables may not be truly autonomous, and the resultant relationships and forecasts may well be void. Trip generation by cross-classification worked as a substitute methodology (Stopher et al. 1983). Dynamic analysis of trip generation and trip generation models were focussed with stable unseen effects (Meurs 1990).

When a country is multinational, the widely varying socioeconomic characteristics of households can lead to sparse data (Said and Young 1990). Another disadvantage relates to the absence of a goodness-of-fit measure of performance and the variation in the reliability of trip rate due to the variation in the number of households available in each cell for calibration. It is reliable only where transport systems in operation and land-use patterns have not undergone major changes (Chatterjee et al. 1977; Kitamura 1981; Morlock 1978). Development of both work and non-work trips of an afternoon peak period trip generation model were studied (Kumar et al. 1993). Three data sources are used in model preparation, a Census-Update Study, a Household Travel Study, and a trip generation study. Seven trip purposes of one-direction are considered, particularly accounting for stops made on the homecoming trip from work to home. Before estimating the model, the Household Travel Study was calibrated against the Census-Update to minimize population bias. A model of home-end trip generation is approximated using the Household Travel Study as a cross-classification of the population factors of age and household size besides house type. Non-home-end generation manipulates employment by category and demography. Development of symbolic trip-generation models from current year database for building prediction of travel in succeeding years were included (Rengaraju et al. 1994). Characteristics of the household are cross-categorized with the existing information, evident cross-categorized cells may become insufficient data. Under such situations, standard application of classification analysis may not be suitable. To overcome this complexity, a linear statistical model structure was developed. Formed models were demonstrated for the diverse cross-categorized plans.

Details about classification analysis in the four-step model article were discussed by McNally (2000). Different methods for tackling the blank cell problem of conventional cross-classification analysis was explored (Badoe et al. 2011). Data points used in the study were gathered in the Toronto area in 1986, 1996, 2001, and 2006. Various models, developed on every year's data, were evaluated for how correctly empty-cell calculated travel at the level of disaggregated household and the aggregate travel analysis zone level in the relevant years. As a supplement, these alternative models predicted on the 1986 data were evaluated for their ability to duplicate travel in 1996 and 2006. The results explain that a process designed by

Mandel (2010) and the model developed in this work, approximates the household trip rate for a blank cell, largely give the best estimate of traffic. Forecast performance of a conventional cross-classification method and other methods that seek to tackle the deficiencies of conventional cross-classification analysis, particularly when it has cells with insufficient data were analysed (Judith et al., 2012). This work uses five datasets gathered in the San Francisco Bay Area in 1965, 1981, 1990, 1996, and 2000. Authors reveal that it is best practice to produce trip rates for just those cells of the cross-classification matrix with insufficient data instead of adjusting the full trip-rate template as is presently the practice. Home-Interview survey was carried out to gather data on trips, purposes on standard workdays and holidays (Hashem et al 2018). Characteristics of socio-economic status of households were also acquired through field surveys. Regression analysis and cross-classification methods were used to model trip generation rates. Analysis of this study indicated that the number of generated trips dependent on family size, income level and car ownership. On workdays, the number of home-based work trips constitutes roughly one-third of the whole home-based trips. Also, it was established that the number of trips on holidays stands approximately one-third of the number of trips generated on workdays. From the analysis, cross-classification technique demonstrated to produce more precise values.

2.2.2. Linear Regression Model

In statistics, linear regression is an approach to model a relation between dependent and independent variables. If there exists an independent variable, then a simple linear regression technique is used. In case of more independent variables, multiple linear regression approach is adopted. Multiple linear regression is as shown in the following form:

$$Y=a_0+a_1*X_1+a_2*X_2+........ \quad (2.1)$$

Where,

Y=Dependent Variable

X_1, X_2,.............. = Independent Variables

a_1, a_2, ... = Coefficients of independent variables; a_0 = Constant

Multiple linear regression is one of the popular methods that can be used to model trip generation (Ortuzar and Willumsen 2001). For trip attraction modelling, independent variables area, zonal employment level, office floor space were considered (Meyer et al. 2001). Purpose of research was to operate collected traffic counts to guess directly area-wide, trip production rates for all purposes was stated (Neumann et al. 1983). The methodology disperses and gives zonal socioeconomic characteristics openly to the study network. External-Internal and Internal-external trips must abridge ground counts. The remaining, reduced counts are put into a linear regression model as the dependent parameter, and the assigned social and economic characteristics are entered as the independent parameter. The resulting regression coefficients are calculations of the area-wide, production rates for all purposes. The methodology was experimented in Lynchburg, Virginia and Lexington, Kentucky. Calculated production rates were within 96% of actual rates.

Ordinary least-squares (OLS) regression is traditionally applied by transportation analysts to predict trip productions, trip attractions, vehicle emissions, pavement condition, energy use, Vehicle Mile Travel growth, and crash incidence (Washington 2000). A major challenge, when approximating OLS models, is to derive a proper condition. Familiar misspecification errors include oversight of critical variables, the inclusion of independent parameters, and the addition of variables in an erroneous functional form. These inaccuracies often give biased parameter approximations, ineffective parameter approximations, and lack of ability to conduct precise hypothesis investigations. Analysts depend on earlier experimental research, and original theory to find suitable model functional structures, to find important relations, and to obtain justifiable models. Public housing development and its traffic impacts on the road system, especially in already most busy cities were studied (Yam et al. 2000). Hong Kong is one of the busiest cities in the world and has a good amount of housing in the city. This study developed a multi linear regression model to predict traffic generation to high density, large scale, multi-storey public residential accommodation estates in Hong Kong. Regression analysis was considered for model appraisal. Parameters such as population, gross floor area, apartments, the accessibility and, parking spaces were incorporated into the analysis. Thus, the model formed is reasonably good both qualitatively and quantitatively.

Four-stage process is widely used in the United States and other places due to institutional and fiscal necessities (Kwigizile et al. 2009). The first step, Trip generation analysis, is based on traffic analysis zones (TAZ) which are geographical units. The zonal trip generation sums are observations calculated at diverse geographical locations. Geographical distribution of the interpretation limits the methods that can be useful in analyzing the data and authorizes the conclusions that can be attained. This study experienced for the attendance of spatial autocorrelation in the variables of trip attraction and production. They proposed four different methods for explaining geographical relationship: a) contiguity, b) separation, c) combined contiguity and separation, and d) economic linkage. Trip attraction model showed that the model proposed using geographical relationship matrix with elements explained by separation was the best built-in. Present methods of traffic impact analysis, which depend on rates and amendments from the Institute of Transportation Engineers, supposed to devalue the traffic benefits of mixed-use developments (MXDs), leading to higher exactions and development charge than required (Ewing et al. 2011). This study has carried out to make novel methodology for accurately assessing the traffic impacts of MXDs. Home Interview surveys and geographic information system (GIS) databases were collected for these MXDs. Traffic and built environmental parameters were defined regularly throughout the study area. Systematic Modelling was used to find out models for internal trips within mixed developments. They also assessed walking and travel use on external trips, and trip length for external vehicular trips.

Trip generation models based on mixed-use and transport infrastructure at the location were studied. These are considered with a plan to better the correctness of trips generated. Information practices are examined, and “smart growth” norms that could affect the correctness of trip generation models are also acknowledged (Nadezda et al., 2013). Investigational results of transport generated trips established on linear regression equations and “smart growth” tools are established. Superior trip generation/attraction models were formulated. A multiple linear regression (MLR) model has been developed from traffic zonal information. These models are evaluated with other estimates by analyzing their premise and the necessary changes (Alexandre et al., 2014). Moreover, these generation/attraction models allowing spatial correlation are planned, and their developments relating to earlier models not taking into considerations of spatial correlation are analyzed. A comprehensive spatial correlation model that performs a joint evaluation of each unit in the sample to find out whether the spatial entities are arbitrarily scattered or in agreement with a particular pattern is specified. To judge cluster conditions in a given region, a native spatial correlation model intended to assess the spatial autocorrelation to file every observation is defined. The models are used to the Santander metropolitan area in Spain to get advanced generation/attraction models in that city.

2.2.3. Trip Generation based on Panel and Count Data

In general, the linear regression models has been used for trip production or attraction of trip generation (Goulias and Kitamura 1989; Monzon et al. 1989; Goulias et al. 1990). These models suffer from several methodological limitations and practical inconsistencies which have been repeated by studies (Lerman et al. 1980; Ivan et al. 1997). Count data models were developed. Problem of standard models based on divisional data only report for effective trip generation was studied (Kitamura 1998). Unusual model formulations are studied with the help of a panel data group to establish whether fundamentals associated with past time data is well thought out in the analysis of trip generation. The analysis illustrates that approximated model coefficients and t-statistics vary considerably based on model requirements. This analysis permits the successive correlation, delayed dependent parameter and considerably enhances the model's fit. This significance of the successive correlation, which apparently is due to absent variables that are longitudinally linked, implies that vital determinants of trip generation be arranged outside the set of parameters that have conventionally been considered in the analysis of travel behaviour. Count data models to defeat the inadequacy of linear regression model used for standard four-step travel demand method was proposed (Jang 2005). The Poisson model with an assumption of equal spreading has commonly been used for the analysis of count data. Nevertheless, if the variance of data is larger than the mean, the Poisson model is likely to undervalue errors, consequently hindrance in consistency. The negative binomial model and the modified count data models are created to take into account of over spreading and non-homogeneity to get a better consistency. The best model is selected through Vuong test. Model consistency is also verified by likelihood test and correctness of approximated value of model by Theil inequality coefficient. Finally, sensitivity analysis is carried out to recognize the variation of non-home based trips depending on socio-economic. Zero-adjusted count data analysis process was elaborated by Gupta et al. (1996).

In the planning of fresh regional prisons in West Virginia, a trip generation data for correctional facilities was taken (French et al. 2000). Five local prisons and one federal correctional facility in West Virginia were intentionally studied. First, trip rates were estimated for the regional jails. The local jails were a homogenous grouping of correctional facilities with service type and size, the trip rates determined for the regional prisons are consistent. Second, the local prison information was produced with data from the Institute of

Transportation Engineers (ITE) and the federal correctional facility in West Virginia. The services were non-homogenous with size or service type. It was determined that both the service type and size have an important impact on the trip rate. Trip rates were estimated for the more broad grouping of ‘‘correctional facilities" based on the manufactured record. Opportunities of creating trip generation models using data collected at two or more locations with independent cross-sectional travel surveys conducted in the given urban area was investigated (Badoe et al. 2004). The other methods for preparing an estimating model based on the presence of cross-sectional data from two time periods are presented. Models are then projected on the study data and the models were evaluated regarding their ability to repeat the number of trips made at disaggregate household level, and at the collective traffic zone level in the two model-estimation datasets, respectively. The functioning of these jointly predictable models is matched up to the predictive performance of a traditional single cross-section trip generation model. These models are then applied to estimate trips at the disaggregate household level, and at the collective traffic zone level on a third independent cross-sectional dataset gathered in the same urban area but at various time periods. Residential trip generation rates are a basic constituent of transportation planning (Miller et al. 2006). To examine inconsistencies in these rates, trip generation rates for nine suburban regions were worked out using four separate methods: a) ground traffic counts conducted in the regions, b) household surveys distributed to the regions, c) application of trip generation rates given by the Institute of Transportation Engineers ITE, and d) rates imitated from the trip generation constituent of urban travel demand models for the regions. Agencies used one of the above rates, and by shaping all four for the same set of areas in a study, it can be established, the extent to which these rates are exchangeable. Rates based on these three methods were not notably unusual. For developments, data is collected exclusively from single-family detached homes, the typical residential trip generation rate was 10.8 based on the ground counts selected for a specific site, 9.2 based on site-specific home interview surveys, and 9.6 based on Institute of Transportation Engineers Trip Generation Rates.

Trip generation models obtained can be transferable by using transfer estimators (Ben-Akiva et al. 1987; Koppelman et al. 1982; NCHRP 1978; Wilmot et al. 2001). Study on accessibility - trip generation dependency was conducted (Kröger et al., 2018). The study leads to the outcome that spatial connectivity of the household site has a comparatively little influence on personal trip rates, in contrast to social, demographic and economic characteristics of the household. Further, study results support the hypothesis that major spatial effects still take place for substitutable activities.

2.2.4. Models based on Neural Network

Study to compare the comparative correctness of various forms of trip generation of migration traffic was conducted (Wilmott et al. 2004). The traditional participation rate, logistic regression, and different outlines of neural network models were studied and tested using a data set of migration activities collected in southwest Louisiana following Hurricane Andrew. The data was separated into a 350-household database on which the logistic regression and neural network models were predicted, and a different 60-household database on which all models were studied. Limited and comprehensive model inputs were tested among various neural network models to decide whether complete specifications to improve the performance of the models. Comparison of the performance of the models in this learning demonstrated that the neural network and logistic regression models were able to estimate evacuation more precisely than the participation rate model. Various neural network applications (Dia 2001; Jiang et al. 2005; Celikoglu et al. 2007; Hu et al. 2010; Centiner et al. 2010) in modelling public transport trips, traffic flow prediction modelling, traffic flow forecasting were worked by various researchers. The neural network concept is also applied to time series prediction of traffic and transit trip estimations (Chan et al. 2012; Sucheta et al. 2012; Kumar et al. 2013; Garrido et al. 2014; Rashi Agarwal et al. 2015).

2.3. Comparison of various Methods

Present transportation planning models are prepared for estimation of cross-sectional data, hence are referred to as cross-sectional demand models. These works have demonstrated the theoretical and practical significance of developing travel demand models based on panel data (Kitamura 1988; Kitamura 1990; Meurs 1990; Goodwin et al. 1987; Michael et al. 2002 and 2006). In common, residential trip generation rates are underreported by the residents, especially trips that are not made with consistency. For example, retail trips are probably underreported than trips for work purpose (Reid 1982; Kumar et al. 1993). Modelling of small urban regions using single internal trip purpose was carried out by Anderson (2001). Models based on tree concept were introduced by Clark et al. (1992), Belmont (1993) and Washington et al. (1997).

In planning transportation region, Ma et al. (1999) have significantly kept effort in the field of activity generation by using the Poisson model but concluded that its assessment is not satisfied. Bhat et al. (1998) worked on the frequency of shopping activities at household level through count data model. Yam et al. (2000) formulated a multi linear regression model to assess traffic generation to high density, large scale, multi-story public residential accommodation estates in Hong Kong. Population, gross floor area, apartments, the accessibility and, parking spaces are the parameters incorporated into the analysis.

Models were prepared for the trip generation at city level using either multiple linear regression analysis or cross-classification/category analysis. Of these two, the cross-classification analysis is more universally adopted (McNally 2000) with applications in passenger travel (Guevara et al. 2007) and also freight (Bastida et al. 2009). These methods are detailed in various documents (Meyer et al. 2000, Ortuzar 2001).

Multiple classification analysis (MCA) is proposed as another method for addressing the problems of cross-classification analysis (Stopher et al. 1983, Breiman et al. (1984)). MCA is same as the analysis of variance (Retherford et al. 1993). Rengaraju et al. (1994) formulated a linear model, which had categorical and continuous variables specified, to predict the trip-rate values for the cells of a cross-classification matrix.

Practical procedure was addressed for estimation of trip generation and chaining, recursive model system (Monzon et al. 1989; Goulias et al. 1989, 1990; Rhee 2003; Ulmer 2003; Nelson et al. 2005; Nadezda Zenina et al. 2013). Impacts of reduction in the vehicle trips for the transit-oriented housing was discussed by Cervero et al. (2008). Land-use and travel interaction was worked out by Ewing et al. (2001, 2010). Count data models are prepared to conquer the inadequacies of linear regression model used for trip generation in conventional four-step travel demand assessment (Jang 2005). Trip generation rates for residential area is important aspect of transportation planning for a region (Miller et al. 2006). To examine the inconsistency in these rates, residential trip generation rates for nine suburban regions were calculated using four dissimilar ways. The comparative statement of various methods are given in following Table 2.1.

Table 2.1: Comparative statement of various methods

S.No.	Method	Authors who worked on the Method	Merits	Demerits
1.	Cross-Classification / Category Analysis	Stopher et al. (1983); Meurs (1990); Kumar et al. (1993); Retherford et al. (1993); Rengaraju et al. (1994); Rengaraju et al. (1994); McNally (2000); Meyer et al. (2000), Ortuzar (2001); Guevara et al. (2007); Bastida et al. (2009); Badoe et al. (2011); Hashem et al., (2018)	1. Cross-classification groupings are independent of the zone system of the study area. 2. No prior assumptions about the shape of the relationship are required. 3. Relationships can differ in shape from class to class (e.g. The effects in changes in the household size for one or two car owning households may be different)	1. There is no statistical goodness-of-fit measure for the model, so only aggregate closeness to the calibration data can be ascertained. 2. The model does not permit extrapolation beyond its calibration strata, although the lowest or highest class of a variable may be open ended
2.	Linear Regression Model	Reid (1982); Neumann et al. (1983); Clark et al. (1992); Kumar et al. (1993); Belmont (1993) and Washington et al. (1997); Yam et al. (2000); Washington (2000); Ewing et al. (2011); Alexandre et al., (2014)	1. Easy for estimation of trips. 2. Performance parameters like R-Square, Mean Square Error (MSE), t-test and F-Value are available for comparing various models.	1. Independent variables are not truly independent. 2. All variables are not normally distributed. 3. As this method uses statistical technique, all the drawbacks related to statistics exist.
3.	Trip Generation based on Panel and Count data	Koppelman et al. (1982); Ben-Akiva et al. (1987); Monzon et al. (1989); Goulias et al. (1989, 1990); Goodwin et al. (1987); Kitamura (1988); Kitamura (1990); Meurs (1990); Gupta et al. (1996); Kitamura (1998); Michael et	1. It is adoptable to smaller areas of interest.	1. It is not suitable for larger urban areas.

S.No.	Method	Authors who worked on the Method	Merits	Demerits
		al. (2002) and (2006); French et al. (2000); Wilmot et al. (2001); Rhee (2003); Ulmer (2003); Nelson et al. (2005); Bhat et al. (1998); Jang (2005); Miller et al. (2006); Badoe et al. (2011); Nadezda Zenina et al. (2013); Kröger et al., (2018)		
4.	Models based on Neural Network	Dia (2001); Wilmott et al. (2004); Jiang et al. (2005); Celikoglu et al. (2007); Hu et al. (2010); Centiner et al. (2010); Chan et al. (2012); Sucheta et al. (2012); Kumar et al. (2013); Garrido et al. (2014); Rashi Agarwal et al. (2015)	1. It is more suitable to capture the non-linearity in the relation between various parameters. 2. In most of the research works, ANN has performed better than other models.	1. As there are numerous combinations exist in choosing training functions, hidden neurons, training algorithm, it is difficult to arrive at a better combination.

2.4. Gaps in Present Research Work

In spite of various trip generation studies like Cross-classification, Linear Regression, count data and neural network techniques, there is a great need for improvement in this topic. Not much work was carried on Trip Generation studies for developing and under-developed countries. Application of Principal Components and Artificial Neural Networks was not explored for Trip Generation Studies. Quick estimates of trip generation rates for developing countries has become a field of uncommon focus. Keeping this in view, trip generation rate estimation process is studied for the developing country like India.

2.5. Scope of Present Work

Regression models are simple and widely used. The extent of the work is to develop regression models for trip rate prediction and neural network models for trip rate estimation. Efforts were put in the application of Principal Component Analysis to reduce the multiple input variables. Models were compared in terms of their performances for various combinations of ANN. In order to estimate Trip Rate instantly, Nomograms were developed.

2.6. Summary

In this chapter, a thorough review of literature related to different methodologies adopted for trip generation was carried out. Techniques were grouped into cross-classification analysis, linear regression, count data and Artificial Neural Network (ANN). Comparison of various models, area of improvement in the current research work and scope of the present work were discussed.

Chapter 3

Study Methodology

3.1. General

In this chapter, methodology used for the research work has been discussed. It includes city categorisation, linear regression models, and ANN models formulation. Principal Component technique is detailed. Development of Nomograms for Trip Rate for various city categories is also presented. The flow of activities has been illustrated in this chapter.

3.2. Methodology Adopted

The methodology adopted to assess the trip rate for various city categories is shown in Figure 3.1. The following are the sub-activities of the study methodology.

1. Selection of cities and categorization
2. Variables Considered / Identified
3. Regression Analysis
4. Principal Component Analysis (PCA)
5. Artificial Neural Network (ANN) Models
6. Development of Nomograms

3.2.1 Selection of Cities and Categorization

Cities with consistent data availability are selected for the study. As the city with various population sizes have different behaviour, in line with National Transport Development Policy Committee, cities have been categorized into three groups. First categories of cities are those cities, whose population is less than 10 lakhs, indicated by CP1. Followed by this category, cities whose population ranges from 10 to 40 lakhs are indicated by CP2. Lastly, cities of the population more than 40 lakhs are denoted by CP3. The categorization of cities based on population is given Table 3.1.

Table 3.1: Categorization of Cities by Population Size

City Category	Population (in Lakhs)
CP1	<10 Lakhs
CP2	10-40 Lakhs
CP3	>40 Lakhs

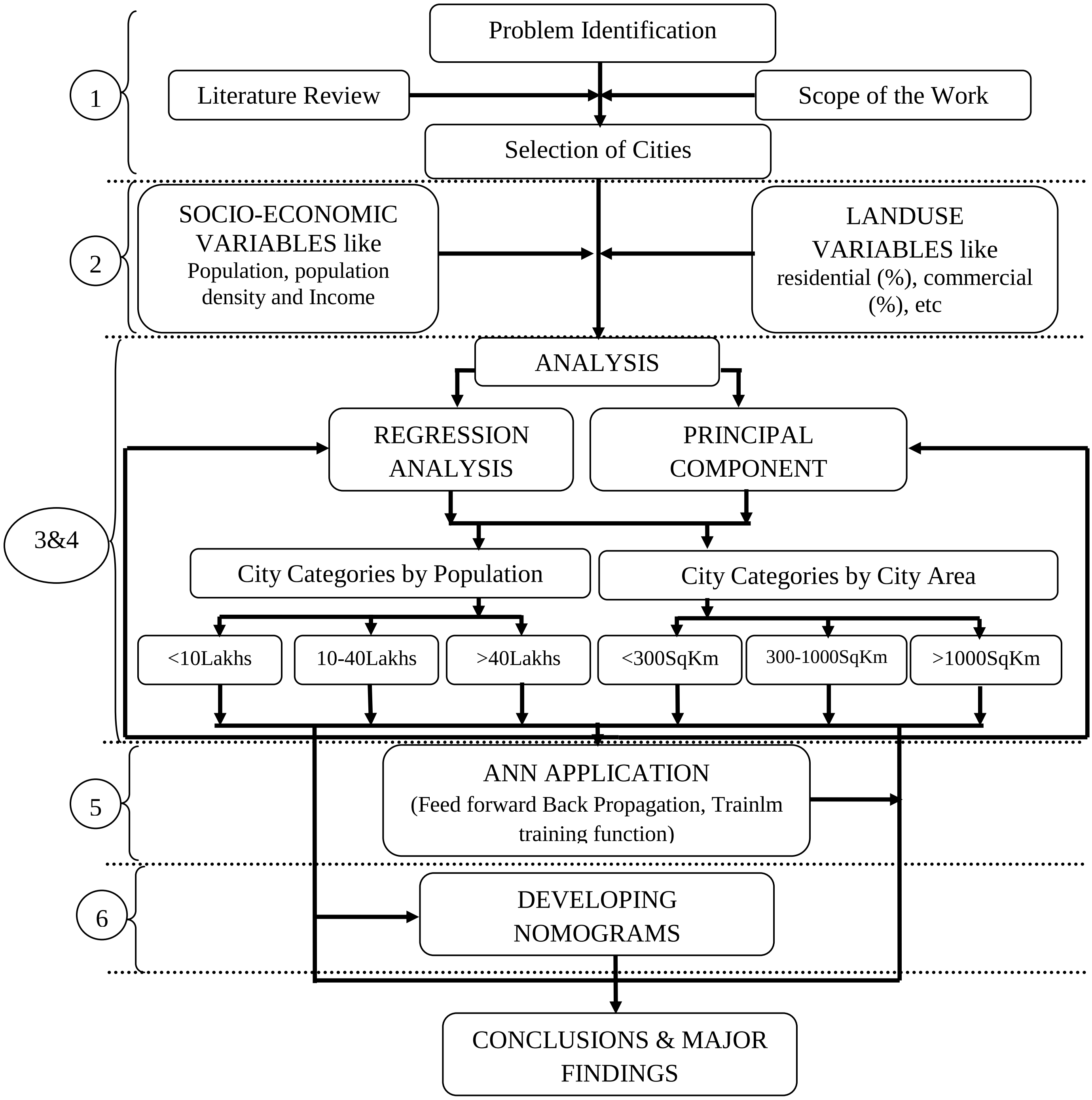


Figure 3.1: Flow Chart of the Research Work

Cities are also growing in area with time. The changes in the area will lead to change in the behaviour of city traffic. Based on city areas given in Indian city statistics (nriol.com/india-statistics/biggest-cities-india.asp), Cities are categorized into three types based on city area (or) extent. Initially, small cities with area less than 300sqkm are denoted as CA1. Medium size cities with area ranging from 300 to 1000 sqkm are denoted as CA2. Finally, large cities with area more than 1000 sqkm are denoted as CA3. Cities categorized based on area are given in Table 3.2. Cross categorisation of cities available for the study is presented in Figure 3.2.

Table 3.2: Categorization of Cities by City Area

City Category	City Area (sqkm)
CA1	<300sqkm
CA2	300-1000sqkm
CA3	>1000sqkm

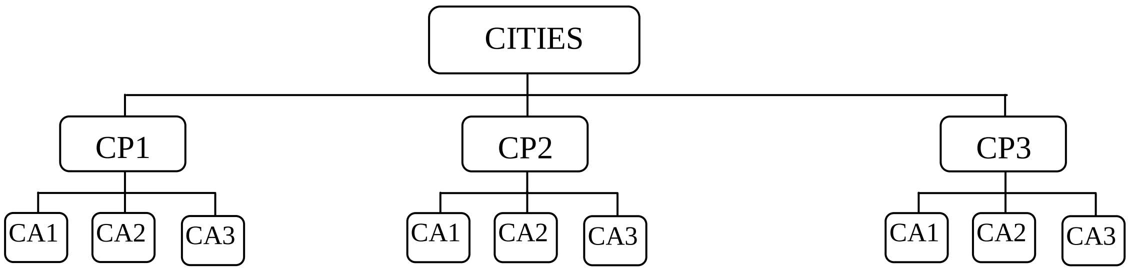


Figure 3.2: Combination of City Categorisation for the study

3.2.2 Variables Considered / Identified

For trip generation modelling, various researchers have used various input variables. The details of these are presented in Table 3.3.

Table 3.3: Authors and data considered for Trip Generation Work

S.No	Authors	Data Considered by the Author for the Trip Generation Work
1	Said and Young 1990	Home Interview data
2	Chatterjee et al. 1977	Home Interview data & Land Use pattern
3	Kitamura 1981	Home Interview data & Land Use pattern
4	Morlock 1978	Home Interview data & Land Use pattern
5	Dunteman 1984	Household Characteristics data
6	Rengaraju et al. 1994	Family size, vehicle ownership & Household Income, etc.
7	Nadezda et al. 2013	Land Use data
8	Clark 2007	Land Use data
9	Alexandre A. Amavi et al. 2014	Socio-economic like family Income, household size and car ownership Land use data like residential, commercial, Institutional
10	Ortuzar and Willumsen, 2001	Land use data like residential, commercial, Institutional
11	Konstadinos G. Goulias, 1990	Household Demographics, Household Socio-economics, Car Availability, City Class
12	Vinodkumar R. Patel et al. 2018	No. of Employees, No. of Males, No. of Females, Income, Plot Area etc.
13	Cervero et al. 1988	Land Use data
14	Martin et al. 1998	Household Interview Data

In line with this, various parameters related to socio-economic and land use were taken for the study. Input variables like land-use data and socio-economic data variables are considered for studying trip rate. Socio-economic variables considered are Population, Area, Population Density, Per capita Income (Rs), City Buses, Road Safety Index, Male (%), Female (%) and registered vehicles. Socio-economic variables data was collected from various sources like Comprehensive Transportation Study (CTS) of different cities, census of India etc. Land-Use variables considered are Residential (%), Commercial (%), Industrial (%), Public (%), Recreational (%) and Transport (%). Land-Use data was taken from Comprehensive Development Plans (CDP) of various cities. For all the models developed in this report, the population is taken in lakhs, population density as the number of persons per square kilometer, City area as square kilometers, and registered vehicles as the number of vehicles in thousands. Details of the Input Variables are given in Table 3.4.

Table 3.4: Details of the Input Variables

S.No	Parameter Type	Parameter	Details
1	Socio-economic	Population	No. of Persons living in the City
2		Area	Extent of the City, sq.km
3		Population Density	No. of Persons per sq.km
4		Male	Out of total population, % of Male
5		Female	Out of total population, % of Female
6		Per Capita Income	Average earning capacity per person, Rs.
7		City Buses	No. of buses plying in the city
8		Road Safety Index	No. of accidents per lakh population
9		Road Density	Length of the road network (km) per sq.km
10		Registered Vehicles	Number of Vehicles Registered
11	Land use	Residential	% Share of residential area
12		Commercial	% Share of commercial area
13		Industrial	% Share of Industrial area
14		Public Area	% Share of public area
15		Recreational	% Share of recreational area
16		Transport	% Share of transport area
17		Agricultural	% Share of agricultural area
18		Water bodies	% Share of water bodies area
19		Open Space	% Share of open space area
20		Other land use	% Share of other area

3.2.3 Regression Analysis

Regression analysis is used to develop a statistical model linking dependent and independent parameters. Linear regression models were formulated for combined cities data and also for categorised cites (i.e., Population category and Area Category) data. Regression analysis was used to uncover significant variables in various models out of total input variables list. Linear regression models were formed for Trip Rate and Motorized Trip Rate with various independent variables like City Area, Population, Registered Vehicles, Per Capita Income and City buses. Results of regression analysis are summarised. Average Trip length (km) was also modeled with various variables like city area, population, population density, registered vehicles, per capita income and city buses.

Trip rate interaction with various socio-economic and land use variables were also worked out. Parameters were processed for development of multi-variable models using multiple regression analysis. For the development of multiple linear regression (MLR) model, the following procedure is adopted.

i. For the selected cities, Parameters such as trip rate, trip length, population, population density, area, per capita income, registered vehicles and land use share were considered.
ii. Variation of socio-economic and land-use parameters was studied with respect to the trip rate for both motorized and all modes individually.
iii. Correlation matrix between these parameters was worked out.
iv. After observing the coefficient of correlation values of this matrix, the combination of variables for the models was identified.
v. Multiple linear regression analysis is carried out for the better mixture of variables and shaping strong relationships.

MLR Equation form: $Y=a_0+a_1*X_1+a_2*X_2+.........$ (3.1)

Y= Dependent Variable, Trip Rate; X_1, X_2= Independent Variables;

a_1, a_2=Coefficients; a_0= Constant

MLR considers a group of random variables and tries to find a mathematical connection between them. Best suited models were derived based on results of statistical performane measures like R-Square, t-stat and F-test.

3.2.4 Principal Component Analysis

Extensive data of socio-economic and Landuse parameters were considered for the study. As the data is multi-dimensional and complex, there is a need to reduce the complexity. Principal component analysis (PCA) is used to reduce the dimensionality of the input matrix. PCA methodology is as shown below.

1. Data for which the dimensions needed to be reduced is selected.
2. Mean of each dimension is calculated and subtracted from the original value. This way the data is adjusted which is easy to represent the data pattern on a plot.
3. Data set whose mean is zero is estimated.
4. Now the adjusted data is used to calculate covariance matrix. The covariance matrix obtained is a square matrix which is based on the dimensionality of the adjusted data. For example, if the adjusted data has five dimensions then covariance matrix would be a 5 x 5 matrix.
5. Non-diagonal elements of the covariance matrix represent the behaviour of the variables.
6. This covariance matrix is used further to calculate Eigen vectors and Eigen values.
7. Eigenvector with the highest Eigen value is then arranged in descending order.
8. Now a feature vector is selected which is nothing but Eigenvectors which are selected for representing the entire data.
9. These Eigenvectors are the principal components which become the major axes and reduce the dimensionality problem.

Example problem of Principal Component Analysis:

X1 X2 X3 X4 X5

Data X= $\begin{bmatrix} 2 & 1 & 5 & 8 & 6 \\ 3 & 4 & 5 & 6 & 3 \\ 5 & 0 & 1 & 3 & 4 \\ 7 & 6 & 5 & 4 & 3 \\ 9 & 2 & 7 & 7 & 8 \end{bmatrix}$=

Centre each column on its mean: X_c=$[X - X(Mean)]$= $\begin{bmatrix} -3.2 & -1.6 & 0.8 & 2.4 & 1.2 \\ -2.2 & 1.4 & -1.2 & 0.4 & -1.8 \\ -0.2 & -2.6 & -3.2 & -2.6 & -0.8 \\ 1.8 & 3.4 & 0.8 & -1.6 & -1.8 \\ 3.8 & -0.6 & 2.8 & 1.4 & 3.2 \end{bmatrix}$

Covariance matrix (2 variables): $S=\frac{1}{n-1} X_c' X_c = \begin{bmatrix} 8.2 & 1.6 & 3.2 & -1.4 & 2.3 \\ 1.6 & 5.8 & 1.6 & -0.7 & -2.6 \\ 3.2 & 1.6 & 5.2 & 3.1 & 3.3 \\ -1.4 & -0.7 & 3.1 & 4.3 & 2.9 \\ 2.3 & -2.6 & 3.3 & 2.9 & 4.7 \end{bmatrix}$

Equation for Eigen values and Eigen vectors of S: $(S-\lambda_k I)u_k=0$

Eigen values: $\lambda_1=12.8$; $\lambda_2=9.4$; $\lambda_3=5.9$; $\lambda_4=0.1$; $\lambda_5=0$

Matrix of Eigen values: $A = \begin{bmatrix} 12.8 & 0 & 0 & 0 & 0 \\ 0 & 9.4 & 0 & 0 & 0 \\ 0 & 0 & 5.9 & 0 & 0 \\ 0 & 0 & 0 & 0.1 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$

Matrix of Eigen vector: $U = \begin{bmatrix} 0.58 & -0.52 & 0.46 & 0.33 & 0.24 \\ 0.06 & -0.59 & -0.64 & 0.19 & -0.44 \\ 0.58 & 0.03 & -0.36 & -0.67 & 0.27 \\ 0.28 & 0.47 & 0.49 & 0.63 & 0.33 \\ 0.48 & 0.39 & 0.21 & 0.03 & -0.75 \end{bmatrix}$

Positions of the 5 objects in ordination space: $F = [X - X(Mean)]U$

$$F=\begin{bmatrix} -3.2 & -1.6 & 0.8 & 2.4 & 1.2 \\ -2.2 & 1.4 & -1.2 & 0.4 & -1.8 \\ -0.2 & -2.6 & -3.2 & -2.6 & -0.8 \\ 1.8 & 3.4 & 0.8 & -1.6 & -1.8 \\ 3.8 & -0.6 & 2.8 & 1.4 & 3.2 \end{bmatrix} * \begin{bmatrix} 0.58 & -0.52 & 0.46 & 0.33 & 0.24 \\ 0.06 & -0.59 & -0.64 & 0.19 & -0.44 \\ 0.58 & 0.03 & -0.36 & -0.67 & 0.27 \\ 0.28 & 0.47 & 0.49 & 0.63 & 0.33 \\ 0.48 & 0.39 & 0.21 & 0.03 & -0.75 \end{bmatrix}$$

$$= \begin{bmatrix} -0.26 & 4.24 & -1.57 & -0.36 & 0.00 \\ -2.67 & -0.25 & -2.04 & 0.54 & 0.00 \\ -3.25 & 0.01 & 3.73 & -0.05 & 0.00 \\ 0.41 & -4.39 & -1.29 & -0.36 & 0.00 \\ 5.77 & 0.39 & 1.17 & 0.23 & 0.00 \end{bmatrix}$$

Cities data categorized based on population and city area is processed to extract principal components for that categories of data. Combined data (Socio-economic and Land-Use) is also processed to get principal components. Models were also developed with principal componenets as input variables. Models with Principal Components is in the following form:

$$Y=a_0+a_1*PC1+a_2*PC2+............... \quad (3.2)$$

where,

Y= Trip Rate, No.of Trips per person per day

PC1, PC2.....= Principal Components

3.2.5 Artificial Neural Network (ANN) Models

To capture the better relation between input and output variables, Artificial Neural Network (ANN) has been applied. Hence, to establish a relationship between Trip-rate of a city with its Socio-economic and Land Use characteristics, the Artificial neural network analysis was employed. Analysis of Socio-economic data and Land use data using Artificial Neural Network has been carried out. Data has been divided randomly in the ratio of 70:15:15. About 70 percent, 15 percent, 15 percent of data is used for Training, Validation and Testing respectively. Based on preliminary analysis, appropriate training function and algorithm was identified.

Artificial Neural Network (ANN) comprises of Input Layer, Hidden Layers and one output layer with connectors. Feed forward back propogation network is used for the study. To start with, Training functions like Trainscg, Trainlm, Traingd, Traingdm, Trainrp, Traincgp, Traincgf and Trainbfg were used to find best training function based on R-Value and mean sqaure error. For further work, this obtained best training function was used.

Combined data (Socio-economic and Land-Use data) is given as input to Artificial Neural Network (ANN) to obtain the Trip Rate/Motorized Trip Rate. Principal components formed by the combined data is given as input to ANN to acquire Trip Rate/Motorized Trip Rate. Data which is categorized based on population and city area is also processed through Artificial Neural Network (ANN) to get better prediction of Trip rate and Motorized Trip Rate. Principal Components of these categorized (based on population and city area) cities information is also given as input to ANN to the output (Trip Rate/Motorized Trip Rate).

3.2.6 Development of Nomograms

Institute of Transportation Engineers (ITE) has developed a manual for trip generation for various small scale land uses. In this manual, a readymade graphs (Nomograms) are available to find the trip generation. However, there is not much work on multiple variable Nomograms for developing country like India.

Pynomo is a sub-module of Python programming. Pynomo software was used to develop Nomograms. Nomograms are created for various categories of cities (Population and Area categories). Types of Nomograms provided by Pynomo is given in Table 3.5. Type 8

Nomograms scripts were used to form the single variable Nomograms. For double variables, Type 1 Nomogram scripts were used (PyNomo).

Table 3.5: Types of Nomograms Provided by Pynomo

Type	Form of Equation	Form of Nomogram
Type 1	$f_1(u_1)+ f_2(u_2)+ f_3(u_3) = 0$	3 Parallel Scales
Type 2	$f_1(u_1)= f_2(u_2)\times f_3(u_3)$ or $f_3(u_3) = f_1(u_1)/ f_2(u_2)$	N or Z
Type 3	$f_1(u_1)+ f_2(u_2)+...+ f_n(u_n) = 0$	Compound Parallel Scales
	$f_1(u_1)+ f_2(u_2)+ f_3(u_3)= 0$ and $f_3(u_3)+ f_4(u_4)+ f_5(u_5) = 0$	3 Parallel Scales Compounded
Type 4	$f_1(u_1) /f_2(u_2) = f_3(u_3)/ f_4(u_4)$	Proportion
Type 5	$f_1(v) = f_2(x,u)$	Contour
Type 6	$u = u$	Ladder
Type 7	$1/ f_3(u_3) = 1 /f_1(u_1) + 1/ f_2(u_2)$	Reciprocal/Angle
Type 8	$y = f(u)$	Single Scale
Type 9	Determinant	General Nomogram
Type 10	$f_1(u)+ f_2(v)f_3(w)+ f_4(w) = 0$	One Curved Line

Methodology to be adopted to form Nomogram:

a. Based on Population and City Area criteria, given data is categorised.
b. Matrices for the categorized data (for both Population and City Area Criteria) with correlation coefficients were formed.
c. Parameters which are in superior relation with Trip Rate and Motorized Trip Rate are selected.
d. Models for Trip Rate and Motorized Trip Rate with those identified variables (1 and 2 variable case) are developed.
e. Script of Type 8 Nomogram was altered to get Nomogram for single variable case.
f. Script of Type 1 Nomogram was altered to get Nomogram for two variable case.

3.3. Summary

Methodology adopted foe the present study has been discussed. Cities have been categorized based on population and city area. Various input variables like socio-economic and land use are considered for trip rate study. Linear regression models for all cities data and for categorised cities were developed. As number of input variables are more, to reduce the complexity, principal component analysis is used. To capture the better models between trip rate and input variables, Artificial Neural Network (ANN) was applied. Based on the models, Nomograms for various city categories will be developed.

Chapter 4
Study Area and Preliminary Data Analysis

4.1. Study Area

India has been predominantly rural throughout the ages, but now many urban centers have flourished from time to time. The country is quickly growing with 30% population residing in urban areas, and this is expected to increase to 66% by 2050 (World Urbanisation Prospects, UN Report, 2018). Estimated number of urban areas is 606, by 2017, in India as per National Transport Development Policy Committee report, 2012. The number of cities with various population ranges are given in Table 4.1.

Table 4.1: Composition of Cities as Per Population Size (Census 2011)

Population in Lakhs	>100	50 to 100	20 to 50	10 to 20	5 to 10	1 to 5	Total
No. of Cities (2011)	3	5	10	25	43	372	458

Source: Urban Transport Report, National Transport Development Policy Committee, 2013.

In the present study, various cities of India are considered for the research work. 450 various cities secondary sources are verified for data availability. However, the following cities were selected based on data consistency as given in Figure 4.1. The population details for the selected cities are presented in Table 4.2 (Census of India, 2011).

Figure 4.1: Selected cities for study

Table 4.2: Cities with population details

S.No	City Name	Population (in lakhs), 2011	Population Range
1	Gangtok	1.00	1-5 Lakhs
2	Panaji	1.45	
3	Shimla	1.72	
4	Bhubaneswar	8.82	5-10 Lakhs
5	Hubli Dharwad	9.44	
6	Guwahati	9.69	
7	Raipur	11.23	10-20 Lakhs
8	Amritsar	11.84	
9	Varanasi	14.35	
10	Madurai	14.62	
11	Agra	17.46	
12	Bhopal	18.83	
13	Patna	20.47	20-50 Lakhs
14	Kochi	21.18	
15	Nagpur	24.98	
16	Kanpur	29.20	
17	Jaipur	30.46	
18	Surat	45.85	
19	Pune	50.50	50-100 Lakhs
20	Ahmadabad	63.52	
21	Hyderabad	77.49	
22	Bangalore	84.99	
23	Chennai	86.96	
24	Kolkata	141.13	>100 Lakhs
25	Delhi	163.15	
26	Mumbai	184.14	

Source: Census of India, 2011

4.2. Data Collection

The data is collected from various sources for different cities, as given below.

1. Comprehensive transportation study (CTS) Reports

2. City development plan (CDP)

3. Comprehensive mobility plan (CMP) Reports

4. Wilber Smith study (Study on Traffic and Transportation Policies and Strategies in Urban Areas in India)

Comprehensive transportation study (CTS)

Comprehensive transportation study (CTS) deals with the study of particular city travel characteristics like identifying travel pattern of residents, a phased program of appropriate and affordable investments and policy, development of the predominant mass transit system and road network.

City development plan (CDP)

CDP is a comprehensive document which is in line with the vision and development approach for the future development of the city, prepared in consultation with a wide range of stakeholders to recognize the thrust areas to be addressed on priority basis to achieve the objectives and the vision.

Comprehensive mobility plan (CMP)

Comprehensive mobility plan is a foresight statement about the way urban transport should develop with the prearranged growth of the city. Comprehensive traffic and transport studies define and prioritize various projects.

Data is also taken from the report "Study on Traffic and Transportation Policies and Strategies in Urban Areas in India" Ministry of Urban Development conducted by Wilber Smith Associates (2008). Details of Data collected from various reports are presented in Table 4.3. Data collected is presented in Table 4.4.

Table 4.3: Data Collection details of selected cities

S.No	**Report**	**Cities**	**Data Collected**
1	Comprehensive Transportation Study	Madurai, Hyderabad, Mumbai	Land use breakup
2	Comprehensive (City) Development Plan	Panaji, Shimla, Raipur, Bhubaneswar, Amritsar, Agra, Bhopal, Kochi, Patna, Varanasi, Nagpur, Jaipur, Kanpur, Ahmadabad, Delhi	Land use breakup
3	Comprehensive Mobility Plan	Surat, Pune, Chennai, Kolkata	Land use breakup

S.No	Report	Cities	Data Collected
4	"Study on Traffic and Transportation Policies And Strategies in Urban Areas in India" by Wilber Smith consultants	All selected cities	Trip Rate, Trip Length, City Buses, etc.
5	Census of India - 2011	All selected cities	Population

Table 4.4a: Data Collected for the Study

City Name	Area (sq. km)	Population (in lakhs)	Population Density (persons/Sqkm)	Per capita income(Rs)	Male %	Female %
Gangtok	35	1.00	2,865	36,075	52.0	48.0
Panaji	29	1.45	4,999	21,348	55.0	45.0
Shimla	76	1.72	2,261	26,075	51.1	48.1
Raipur	226	11.23	4,967	52,689	50.4	49.6
Bhubaneswar	419	8.82	2,105	25,584	53.1	46.9
Hubli Dharwad	202	9.44	4,665	37,576	50.5	49.5
Guwahati	216	9.69	4,484	40,260	52.1	47.9
Amritsar	2,683	11.84	441	50,640	52.9	47.1
Madurai	248	14.62	5,897	46,050	50.2	49.5
Agra	188	17.46	9,270	35,650	53.5	46.5
Bhopal	698	18.83	2,698	58,230	52.2	47.9
Kochi	126	21.18	16,809	48,125	49.3	50.7
Patna	235	20.47	8,720	45,230	52.7	47.3
Varanasi	1,550	14.35	926	40,560	52.3	47.7
Nagpur	218	24.98	11,458	81,225	51.3	48.7
Jaipur	112	30.46	27,198	95,904	52.3	47.7
Kanpur	3,029	29.20	964	98,000	53.7	46.3
Surat	327	45.85	14,023	52,030	55.9	44.1
Pune	710	50.50	7,113	22,178	52.2	47.8
Ahmadabad	464	63.52	13,690	75,115	52.5	47.5
Hyderabad	650	77.49	11,922	77,277	51.2	48.8
Chennai	426	86.96	20,413	21,885	50.4	49.6
Bangalore	741	84.99	11,470	1,10,400	52.2	47.8
Kolkata	1,887	141.13	7,480	26,710	52.4	47.6
Delhi	1,484	163.15	10,994	1,35,820	53.6	46.4
Mumbai	4,355	184.14	4,228	4,30,548	54.6	45.4

Table 4.4b: Data Collected for the Study (Contd.)

City Name	**City Buses (Govt.+Pvt.)**	**Road Safety Index**	**Road Density (Km/Sqkm)**	**Reg Veh**
Gangtok	0	0.04	92	3,977
Panaji	8	0.01	147	1,26,777
Shimla	16	0.06	21	1,39,300
Raipur	0	0.02	4	5,79,000
Bhubaneswar	32	0.05	4	4,22,994
Hubli Dharwad	170	0.04	10	3,12,552
Guwahati	62	0.03	1	3,98,000
Amritsar	0	0.06	2	6,92,791
Madurai	609	0.11	6	6,80,000
Agra	20	0.14	12	4,75,700
Bhopal	240	0.08	2	8,29,000
Kochi	350	0.09	5	3,03,436
Patna	0	0.18	6	4,84,366
Varanasi	0	0.16	1	5,88,000
Nagpur	241	0.10	9	12,36,174
Jaipur	327	0.06	37	7,09,638
Kanpur	176	0.05	0	5,77,896
Surat	106	0.15	5	18,00,641
Pune	824	0.21	19	22,67,000
Ahmadabad	886	0.14	5	9,29,757
Hyderabad	2,546	0.06	5	33,87,000
Chennai	2,816	0.07	7	37,67,000
Bangalore	4,185	0.12	14	41,56,000
Kolkata	4,256	0.32	3	4,96,000
Delhi	6,906	0.08	19	82,93,167
Mumbai	3,430	0.25	5	73,50,000

Table 4.4c: Data Collected for the Study (Contd.)

City Name	**Residential (%)**	**Commercial (%)**	**Industrial (%)**	**Public and semi public (%)**	**Recreational (%)**
Gangtok	23.0	4.0	2.0	8.0	4.0
Panaji	34.0	10.0	0.0	0.0	0.0
Shimla	61.2	1.7	0.6	9.4	0.0
Raipur	26.4	3.4	5.7	23.0	26.7

City Name	Residential (%)	Commercial (%)	Industrial (%)	Public and semi public (%)	Recreational (%)
Bhubaneswar	17.6	1.0	1.8	4.9	1.3
Hubli Dharwad	31.0	3.0	5.0	17.0	6.0
Guwahati	31.7	2.7	2.8	11.0	11.0
Amritsar	29.8	2.8	3.1	5.2	0.9
Madurai	19.1	0.4	0.8	1.9	0.0
Agra	61.8	2.6	6.9	0.0	0.0
Bhopal	47.0	4.0	9.0	12.0	13.0
Kochi	43.4	1.0	5.7	4.2	0.0
Patna	60.9	2.2	1.8	4.8	1.6
Varanasi	51.6	3.5	3.7	7.3	5.5
Nagpur	31.0	2.0	2.0	11.0	0.0
Jaipur	33.1	1.7	3.8	2.8	1.1
Kanpur	62.9	3.3	6.9	0.0	6.8
Surat	41.3	1.4	5.0	0.0	0.0
Pune	42.5	1.6	4.1	6.8	8.4
Ahmadabad	34.9	2.5	15.4	0.0	0.0
Hyderabad	26.6	16.2	1.3	32.7	10.5
Chennai	13.8	0.7	3.2	0.0	4.7
Bangalore	43.2	2.9	6.8	8.7	0.0
Kolkata	31.2	3.3	3.3	0.0	8.1
Delhi	55.0	3.0	6.0	8.0	14.2
Mumbai	27.0	1.0	6.0	4.0	6.0

Table 4.4 d : Data Collected for the Study (Contd..)

City Name	Transport (%)	Agricultural (%)	Water bodies and coastal (%)	Open spaces (%)	Trip Rate(all modes)	Trip Rate (Motorised)
Gangtok	11.0	5.0	0.0	7.0	0.87	0.39
Panaji	3.6	0.0	1.6	0.0	0.78	0.47
Shimla	25.2	0.0	0.0	0.4	0.79	0.33
Raipur	12.6	0.0	0.0	0.0	0.94	0.38
Bhubaneswar	6.2	26.6	11.7	12.9	0.98	0.48
Hubli Dharwad	22.0	16.0	0.0	0.0	0.93	0.54
Guwahati	10.4	0.0	0.0	0.0	0.99	0.58
Amritsar	9.8	35.1	1.1	3.3	1.10	0.53
Madurai	2.2	55.7	18.7	0.0	1.15	0.56
Agra	10.9	0.0	0.0	0.0	1.07	0.57
Bhopal	15.0	0.0	0.0	0.0	1.15	0.65

City Name	Transport (%)	Agricultural (%)	Water bodies and coastal (%)	Open spaces (%)	Trip Rate(all modes)	Trip Rate (Motorised)
Kochi	4.0	20.5	19.0	0.3	1.22	0.98
Patna	7.8	18.9	1.1	0.7	1.23	0.53
Varanasi	8.2	9.4	0.0	0.0	1.13	0.67
Nagpur	17.0	27.0	0.0	0.0	1.30	0.64
Jaipur	9.0	10.6	0.0	0.0	1.25	0.78
Kanpur	10.4	0.0	0.0	0.0	1.21	0.62
Surat	8.0	18.0	0.0	0.0	1.3	0.75
Pune	13.0	0.0	0.0	0.0	1.31	0.88
Ahmadabad	9.4	0.0	0.5	0.0	1.41	0.91
Hyderabad	9.2	0.0	0.4	0.0	1.44	1.01
Chennai	9.1	59.9	0.0	0.0	1.51	1.02
Bangalore	20.7	0.0	0.0	0.0	1.42	0.97
Kolkata	5.5	45.3	0.0	0.0	1.58	1.04
Delhi	12.0	0.0	0.0	0.0	1.58	1.10
Mumbai	16.0	0.0	19.0	0.0	1.68	1.13

4.3. Trip Rate Vs Socio-economic and Travel Characteristics

To study the variation of trip rate and trip length, the preliminary analysis was carried out concerning independent variables like population, population density, area, etc.

Independent variables considered are:

- ✓ Population
- ✓ Population Density (Persons per sqkm)
- ✓ Area (Sqkm)
- ✓ Per Capita Income (Rs./year)
- ✓ City Buses (Nos.)
- ✓ Registered Vehicles (Nos.)

The graphs are generated by considering independent variables on the x-axis, and dependent variables on the y-axis. Corresponding to each of the six independent variables, graphs are plotted as shown in Figure 4.2 to 4.7. From these graphs, the equations are obtained by fitting the trend line to given observations.

Trip Rate / Trip Length VS Population:

Scatter diagram between trip rate and the population is shown in Figure 4.2. From Figure 4.2, it is observed that trip rate value is gradually increasing from 0.8 to 1.7 as population increases from 1 lakh to 185 lakhs. Up to 40 lakhs population, the trip rate varies from 0.8 to 1.3 and from 40 to 185, it gradually increases from 1.4 to 1.7. As shown in the figure 4.2, it can be said that trip rate value increases nonlinearly as population increases and it is only graphical representation. Whereas, trip length varies from 3 km to 13 km for the population ranging from 0.8 lakh to 185 lakhs. The relation between trip length and the population is linear.

Trip Rate / Trip Length VS Population Density:

A graph has been plotted between trip rate and population density as shown in Figure 4.3. In this case, it can be observed that the value of trip rate changes from 0.8 to 1.7 for population density of 440 to 27,000 Persons/sqkm. The relation between trip rate and population density is exponential with growing trend. Whereas, trip length varies from 3 to 13 km for the population density ranging from 440 to 27,000 Persons/sqkm. This association is exponential.

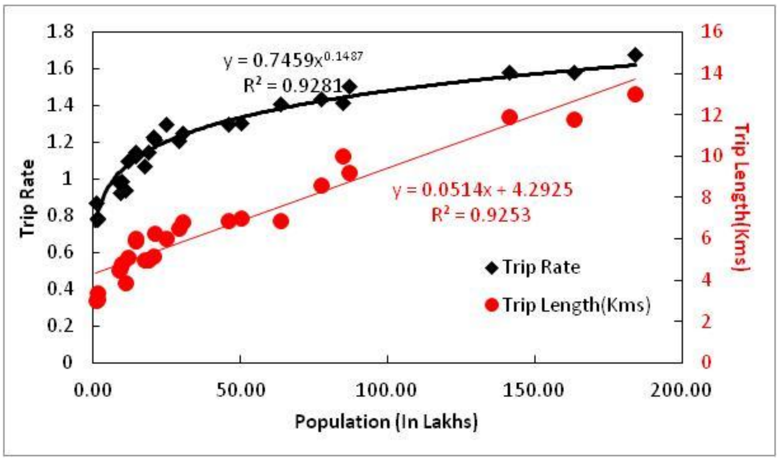


Figure 4.2: Trip Rate and Trip Length vs. Population

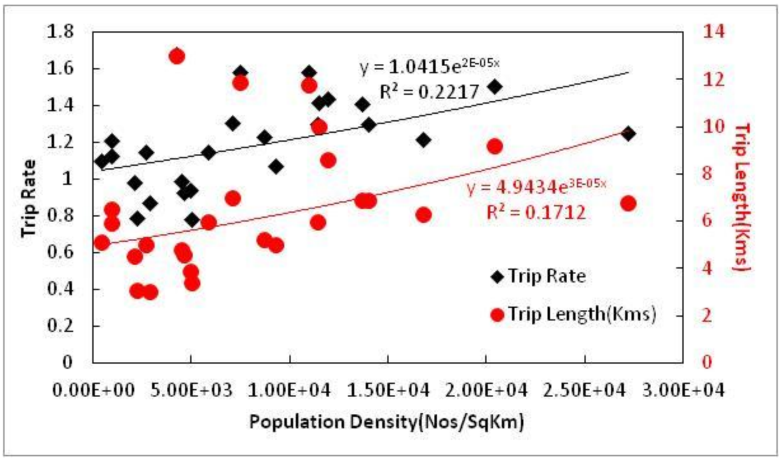


Figure 4.3: Trip Rate and Trip Length vs. Population Density

Trip Rate / Trip Length VS City Area:

A plot of trip rate and city area is shown in Figure 4.4. It can be observed that the value of trip rate fluctuates from 0.8 to 1.7 for city area from 30 to 4,400 sqkm. As the city area increases, the trip rate also increases with a power function. Whereas, trip length varies from 3 to 13 km for the same city area range. And, this relation is also power function. The same variation is presented in this graph.

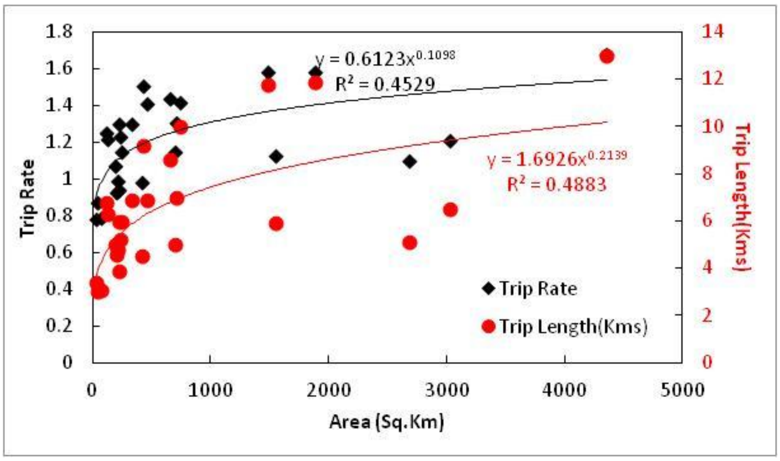


Figure 4.4: Trip Rate and Trip Length vs. City Area

Trip Rate / Trip Length VS Per Capita Income:

A graph has been plotted between Trip Rate and per capita income as presented in Figure 4.5. It is observed that Trip Rate value varies from 0.8 to 1.7 for Per Capita Income 20,000 to 4,30,000. As the Per Capita Income increases, trip rate increases logarithmically. Whereas, Trip length varies with per capita income by way of power function as shown in figure 4.5.

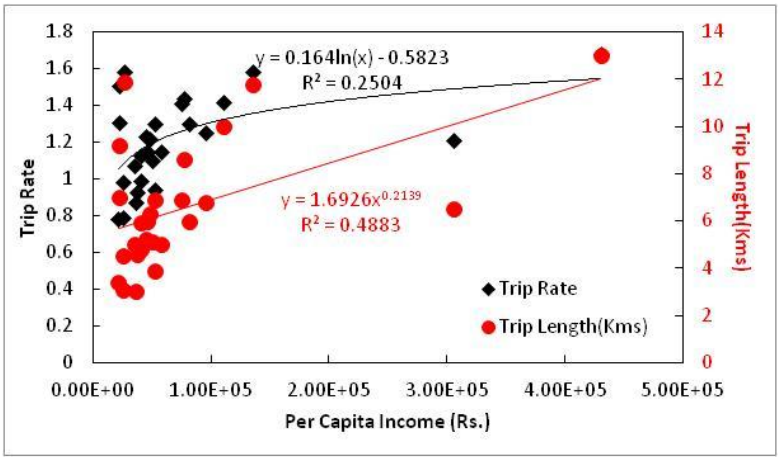


Figure 4.5: Trip Rate and Trip Length vs. Per Capita Income (Rs.)

Trip Rate / Trip Length VS City buses:

The Trip Rate has a linear relationship with the number of city buses up to 7,000. Trip length is also increases linearly with the number of city buses. This variation has been presented in Figure 4.6**.**

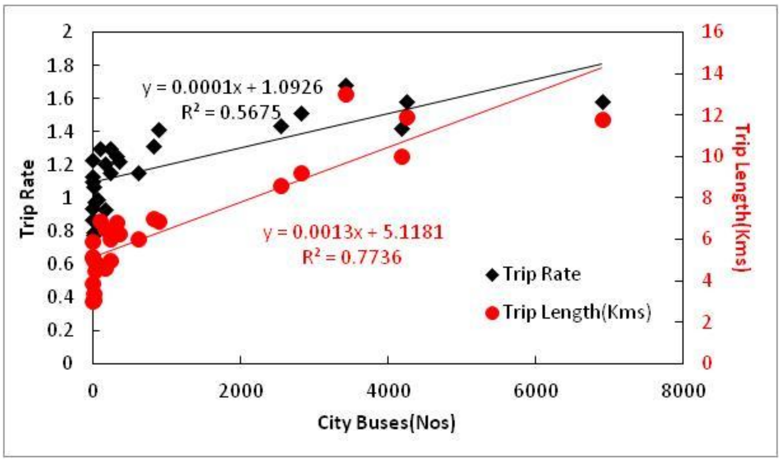


Figure 4.6: Trip Rate and Trip Length vs. City Buses

Trip Rate / Trip Length VS Registered Vehicles:

Out of linear and non-linear models considered, it may be observed that Trip Rate (ranges from 0.8 to 1.7) is linearly related to the Registered Vehicles (4,000 to 83, 00,000). Trip length is also increases linearly with same registered vehicles as shown in Figure 4.7.

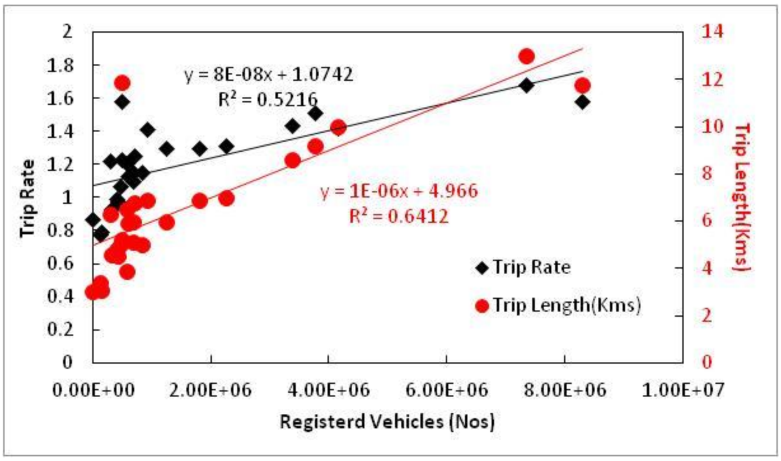


Figure 4.7: Trip Rate and Trip Length vs. Registered Vehicles

The best fit equations with R-square values for Trip Rate and Trip Length are presented in Tables 4.5 & 4.6 respectively.

Table 4.5: Best fit equations with R-square for Trip Rate (TR) Vs Socio-Economic and Travel Characteristics

S.No	**Best Fit Equation**	R^2
1	Trip Rate =0.7459* Population$^{0.1487}$	0.92
2	Trip Rate = 1.0415* Exp (0.00002*Population Density)	0.22
3	Trip Rate = 0.6123* Area$^{0.1098}$	0.45
4	Trip Rate = 0.164*ln (Per Capita Income) + 0.5823	0.25
5	Trip Rate = 0.0001* City Buses + 1.0926	0.56
6	Trip Rate = 8*10^{-8}* Registered Vehicles +1.0742	0.52

Note: Population-In Lakhs; Population Density - Persons/sq.km; Area - sq.km; Per Capita Income - In Rupees; City Buses - Numbers; Registered Vehicles - In Numbers

Table 4.6: Best fit equations with R-square for Trip Length (TL) Vs Socio-Economic and Travel Characteristics

S.No	**Best Fit Equation**	R^2
1	Trip Length =0.514* Population + 4.2925	0.92
2	Trip Length = 4.9434* Exp (0.00003*Population Density)	0.17
3	Trip Length = 1.692* Area$^{0.2139}$	0.48
4	Trip Length = 0.1692* (Per Capita Income)$^{0.2139}$	0.48
5	Trip Length = 0.0013* City Buses + 5.1181	0.77
6	Trip Length = 1*10-6* Registered Vehicles + 4.966	0.64

Note: Population-In Lakhs; Population Density - Persons/sq.km; Area - sq.km; Per Capita Income - In Rupees; City Buses - Numbers; Registered Vehicles - In Numbers; Trip Length - In Kilometres

4.4. Trip Rate Vs Land Use

People can utilize particular land areas in diverse ways. These can include residential, institutional, trade, industrial, farming, forestry, park, and other relatively natural land-uses. Each of these broader categories can be further subdivided, based on the character and strength of the activities that are undertaken.

Residential land use, for instance, can absorb single-family dwelling on large or small lots, or aggregations of multiple unit dwelling of diverse sorts. The mainly concentrated residential land uses are associated with clusters of apartment buildings, which can hold up incredibly great density of human populations.

Institutional land uses are mostly associated with public buildings such as schools, universities, government buildings, art galleries, and museums. These amenities are as a rule, mostly situated in urban or inhabited areas. Business land uses are rather similar in many respects and are mainly connected with the ground that is appropriated to trade facilities of a different type, and with workplace buildings.

Industrialized land use is largely different, depending on the scenario of the industry being considered. Urban industrial land habit, in general, refers to the factory or petroleum refinery, also of utilities such as power generating stations. Industrialized land use in countryside places can take in mines, and mills for the making of ores and metals. Mines and oil well fields for the creation of fossil fuels such as coal, oil, and natural gas. Huge water- held reservoirs are for the production of electricity.

Land uses for agriculture and forestry is meant for food production. They are concerned with the production of food or tree fibre as renewable assets. The existence of agricultural land uses which depends on the type of fields and agronomic system, which can differ from intensively managed monocultures, to more organic systems involving annual or perennial crop. Likewise, the intensity of the land use in forestry differs from patterns linking plain cutting and the enterprise of small alternation plantations, in the direction of selection of harvesting systems with the long spaced intervention.

Quite a lot of land use connected with parks, the golf courses and vacant land. The managing exercises used to keep these ecosystems are same as those that are utilized in some types of agricultural practices. Other types of parks, however, are little altered from the ordinary state of the ground, in addition they could only engage the growth of a highway in roads.

The selected land use parameters are listed below

- ✓ Residential Area
- ✓ Industrial Area
- ✓ Transport Area
- ✓ Commercial Area
- ✓ Recreational Area
- ✓ Agricultural Area
- ✓ Open Space Area
- ✓ Other Area

Graphs have been plotted between various land use shares and Trip rate as shown in Figures 4.8 to 4.13. The value of Residential Area changes from 16.5% to 55% with the trip Rate values changes from 0.8 to 1.6. Commercial Area changes from 0.5% to 3.3% with the values of Trip Rate changes from 1.1 to 1.6. Industrial Area changes from 0.5% to 16% with the values of Trip Rate changes from 0.8 to 1.4. Recreational Area changes from 1% to 14% with the values of Trip Rate changes from 0.8 to 1.6. Transport Area changes from 3.5% to 21% with the Trip Rate values changes from 0.8 to 1.4. Agriculture Area changes from 5% to 60% with the values of Trip Rate changes from 0.85 to 1.6. From graphs, it is shown that the Trip Rate increases with the increase in the Residential Area, Commercial Area, Industrial Area, Recreational Area, Transport Area and Agricultural Area. Trip Rate increases with increase in land use share. The rate of increase of these trip rates varies with various land use types.

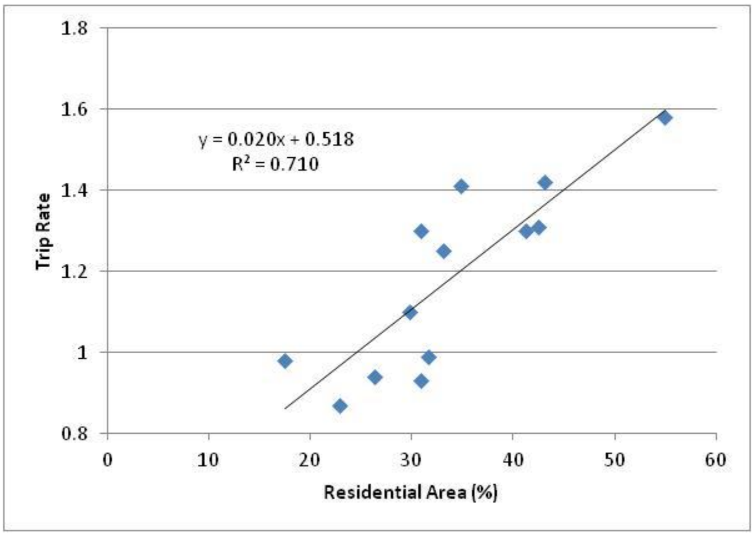


Figure 4.8: Residential Area vs. Trip Rate

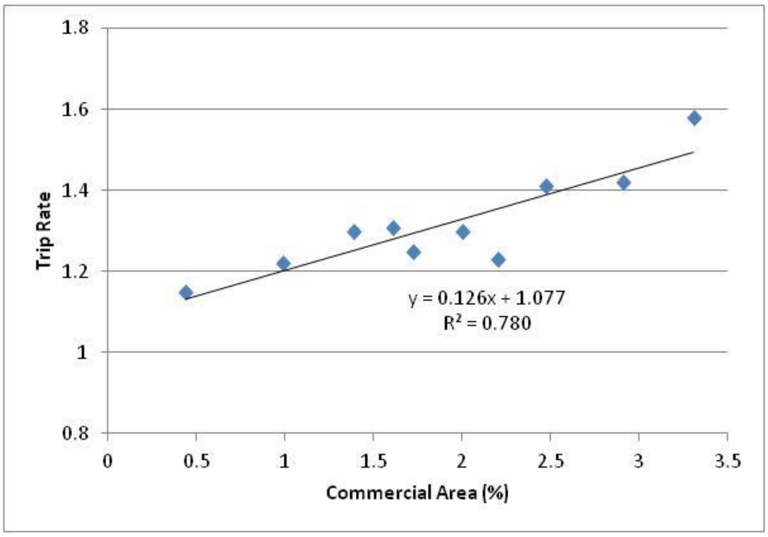


Figure 4.9: Commercial Area vs. Trip Rate

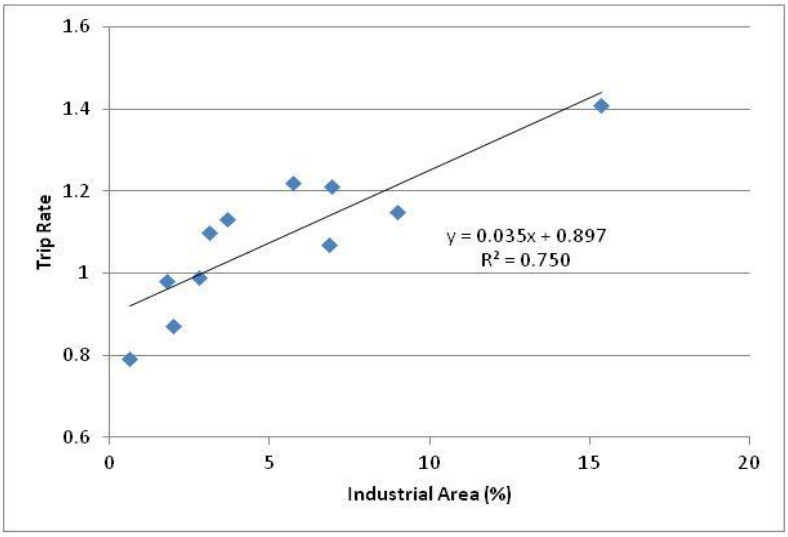


Figure 4.10: Industrial Area vs. Trip Rate

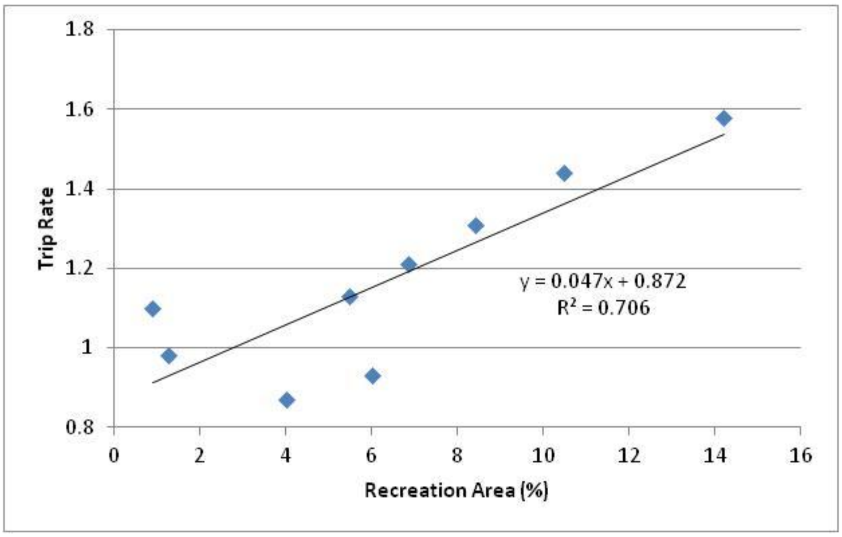


Figure 4.11: Recreational Area vs. Trip Rate

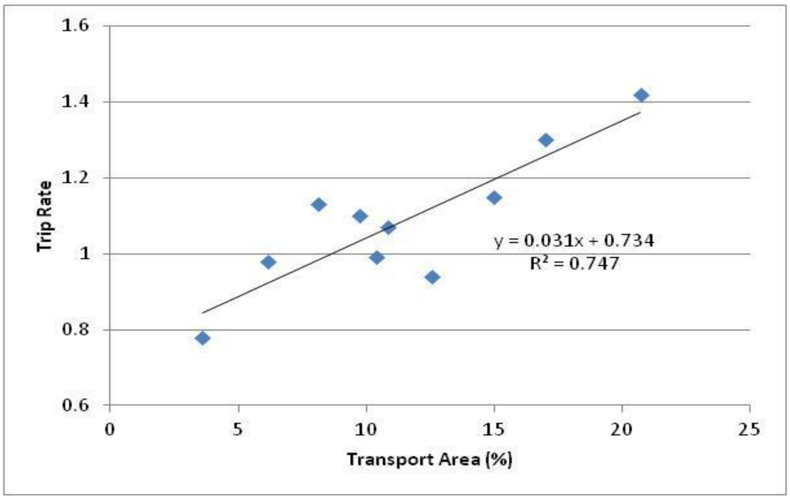


Figure 4.12: Transport Area vs. Trip Rate

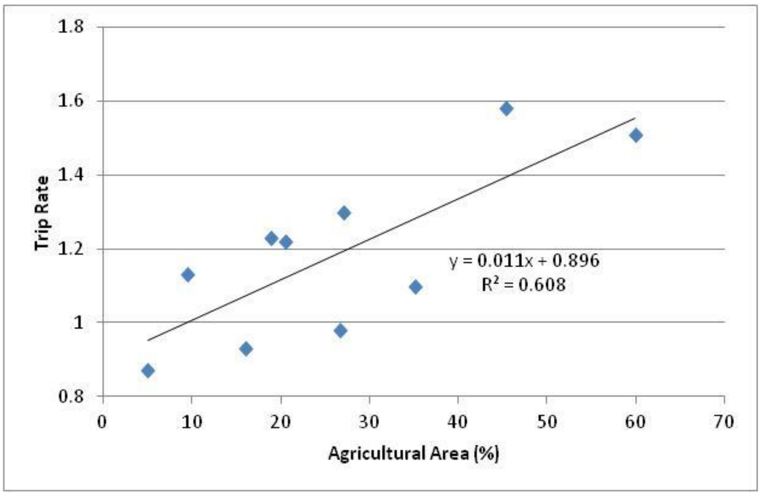


Figure 4.13: Agriculture Area vs. Trip Rate

The best fit equations with R-square values for Trip Rate are presented in Table 4.7.

Table 4.7: Best fit equations with R-square for Trip Rate (TR) Vs Various Land use share

S.No	Best Fit Equation	R^2
1	Trip Rate = 0.020* Percentage Residential Area + 0.518	0.71
2	Trip Rate = 0.126* Percentage Commercial Area + 1.077	0.78
3	Trip Rate = 0.035* Percentage Industrial Area + 0.897	0.75
4	Trip Rate = 0.470* Percentage Recreational Area + 0.872	0.70
5	Trip Rate = 0.031* Percentage Transport Area + 0.734	0.75
6	Trip Rate = 0.011* Percentage Agricultural Area + 0.896	0.61

Graphs have been plotted between various land use share and Motorized Trip rate as shown in Figures 4.14 to 4.19. Residential Area (%) changes from 17 to 55 with the Motorized trip Rate changing from 0.35 to 1.1. Commercial Area (%) changes from 0.4 to 3.4 with the values of Motorized Trip Rate changing from 0.45 to 1.1. Industrial Area (%) changes from 0.6 to 6.8 with the values of Motorized Trip Rate changing from 0.3 to 1.2. Recreational Area (%) changes from 1 to 14 with the values of Motorized Trip Rate changing from 0.46 to 1.16. Transport Area (%) changes starting 3.5 to 21 with values of Motorized Trip Rate changing from 0.48 to 1. Agricultural Area (%) changes from 4 to 60 with the values of Motorized Trip Rate changing from 0.38 to 1. From graphs, it is shown that the Motorized Trip Rate increases with the increase in the Residential, Commercial, Industrial, Recreational, Transport and Agricultural Areas. Motorized trip rate increases with the increase of various land use shares. The rate of increase of Motorized trip rate varies with the type of land use.

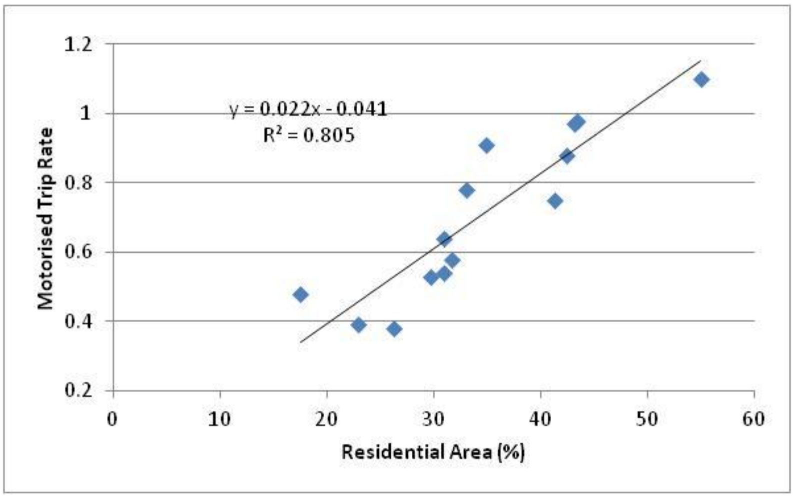


Figure 4.14: Residential Area vs. Motorized Trip Rate

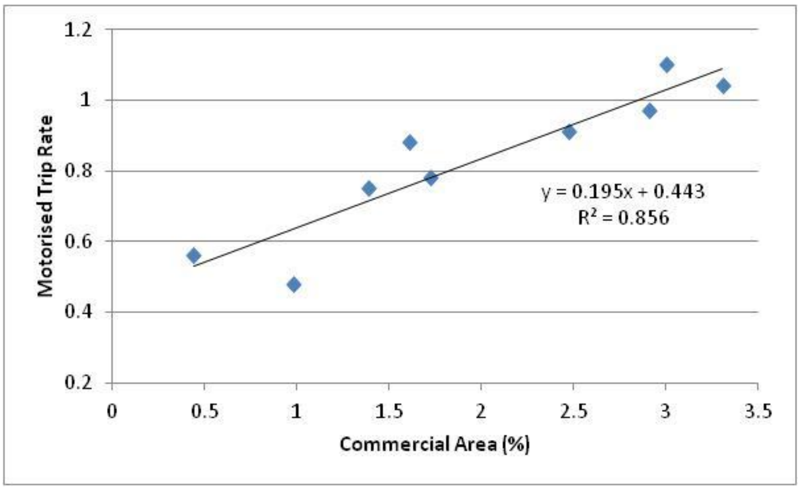


Figure 4.15: Commercial Area vs. Motorized Trip Rate

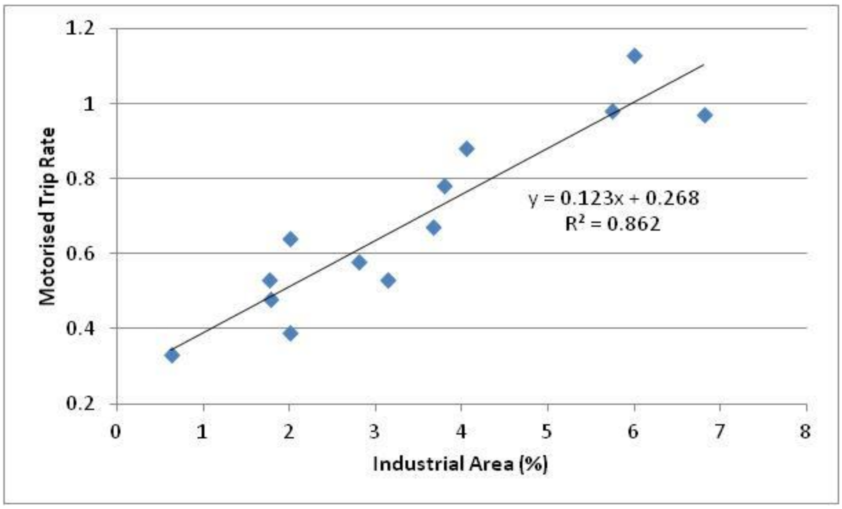


Figure 4.16: Industrial Area vs. Motorized Trip Rate

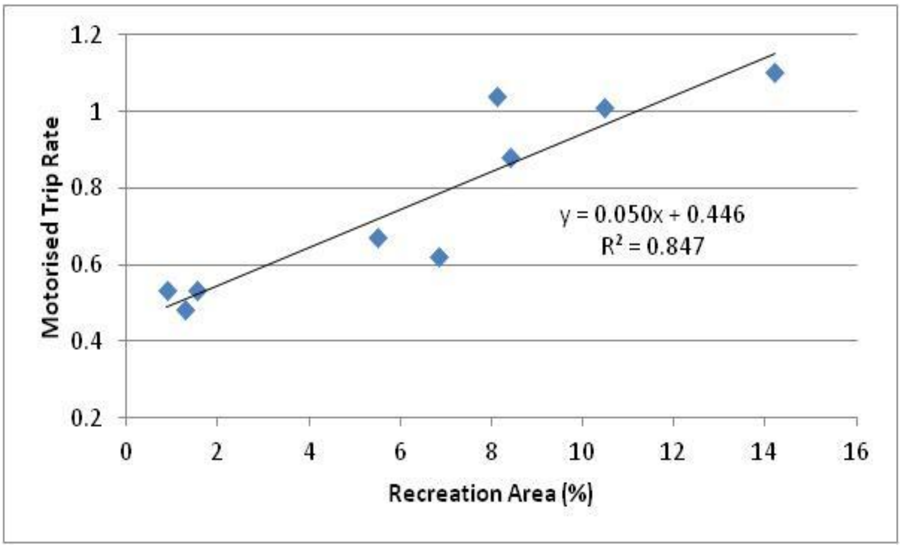


Figure 4.17: Recreational Area vs. Motorized Trip Rate

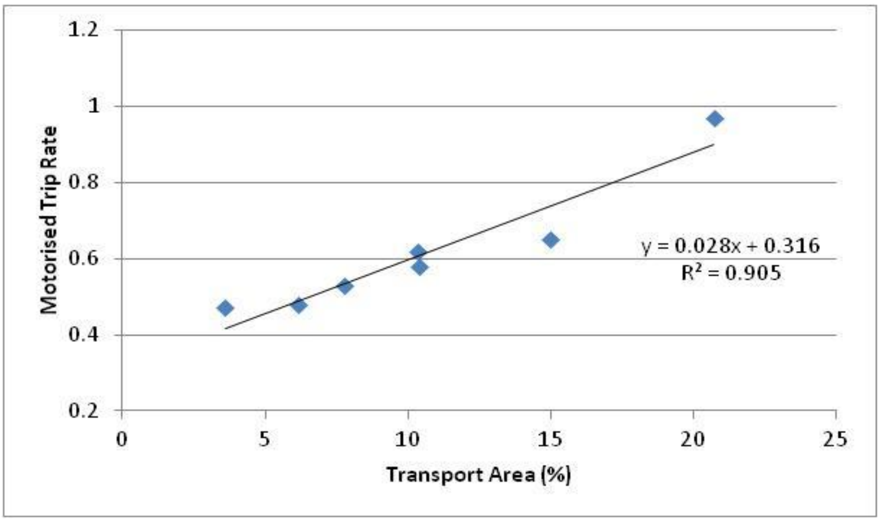


Figure 4.18: Transport Area vs. Motorized Trip Rate

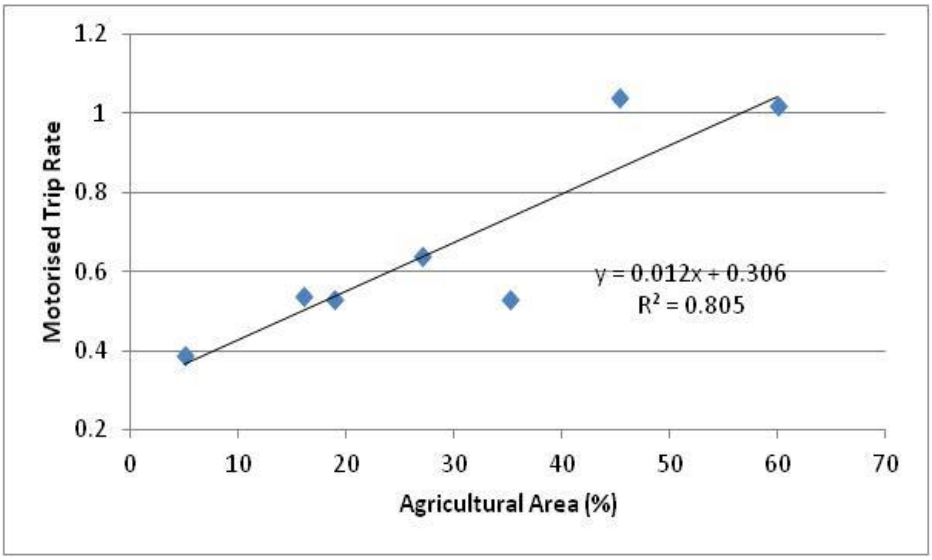


Figure 4.19: Agricultural Area vs. Motorized Trip Rate

The best fit equations with R-square values for Motorized Trip Rate are presented in Table 4.8.

Table 4.8: Best fit equations with R-square for Motorized Trip Rate (MTR) Vs Various Land use share

S.No.	Best Fit Equation	R^2
1	Motorized Trip Rate = 0.022*Percentage Residential Area - 0.041	0.80
2	Motorized Trip Rate = 0.195* Percentage Commercial Area + 0.443	0.86
3	Motorized Trip Rate = 0.123* Percentage Industrial Area + 0.268	0.86
4	Motorized Trip Rate = 0.050* Percentage Recreational Area + 0.446	0.85
5	Motorized Trip Rate = 0.028*Percentage Transport Area + 0.316	0.90
6	Motorized Trip Rate = 0.012* Percentage Agricultural Area + 0.306	0.80

4.5. City Categorization

Cross categorization of cities are given in Table 4.9. As there are less cities avaliable for categories like CP1-CA2, CP1-CA3, CP2-CA2, CP2-CA3, CP3-CA1, CP3-CA3, it is difficult to model these cross categories of cities. For the present work, CP1, CP2, CP3, CA1, CA2, and CA3 groups of data was studied but not CA1-CP1 etc.

Table 4.9: Categorization of Cities

Number of Cities		City Area, Sqkm			Total
		CA1(<300)	CA2 (300-1000)	CA3 (>1000)	
City Population, Lakhs	CP1 (<10)	5	1	NA	6
	CP2 (10-40)	7	1	3	11
	CP3 (>40)	NA	6	3	9
Total		12	8	6	26

Note: NA stands for Data is Not Available

4.6. Summary

This chapter dealt with study area, data collection and preliminary analysis including the variation of trip rate and trip length with various parameters. The interaction of land use with trip rate and motorized trip rate was presented in this chapter.

Chapter 5

Trip Rate Prediction Models

5.1. General

In this chapter, Cities selected have been categorized for developing trip rate prediction models. Principal component analysis technique is used to reduce the dimensionality of the input variables. Trip rate prediction models were formed with principal components. Trip Rate models were also formed with the use of Artificial Neural Networks (ANN).

5.2. Modelling Approach

Models were developed for all cities data, categorised data on the basis of population and categorised data on the basis of city area. Modelling Approach is as follows.

- ❖ To examine the behaviour of each variable with respect to Trip Rate, Simple Linear Regression is adopted.
- ❖ To examine multiple variable behaviour on Trip Rate, Multiple Linear Regression is adopted.
- ❖ To reduce the complexity in terms of number of input variables, Principal Component Concept is used. Models were prepared using Principal Components.
- ❖ To get better models, Artificial Neural Network is adopted using raw data as input.
- ❖ To improve efficiency of the models, Artificial Neural Network is adopted using Principal Components as Input.

5.3. Simple Linear Regression Models

Regression analysis helps to understand how the characteristic value of the dependent variable fluctuates when any one of the independent variables is diverse, while the other independent variables are seized fixed. Most commonly, regression analysis approximates the conditional anticipation of the dependent variable given the independent variables – that is, the average value of the dependent variable estimation when the independent variables are inputted. Data used for Simple Linear Regression is given in Table 5.1.

Table 5.1a: Data for the Simple Linear Regression

City Name	Population Category	Area Category	Area(sq km)	Population (in lakhs)	Population Density (persons/Sqkm)	Per capita income (Rs)
Gangtok	CP1	CA1	35	1.00	2,865	36,075
Panaji	CP1	CA1	29	1.45	4,999	21,348
Shimla	CP1	CA1	76	1.72	2,261	26,075
Raipur	CP2	CA1	226	11.23	4,967	52,689
Bhubaneswar	CP1	CA2	419	8.82	2,105	25,584
Hubli Dharwad	CP1	CA1	202	9.44	4,665	37,576
Guwahati	CP1	CA1	216	9.69	4,484	40,260
Amritsar	CP2	CA3	2,683	11.84	441	50,640
Madurai	CP2	CA1	248	14.62	5,897	46,050
Agra	CP2	CA1	188	17.46	9,270	35,650
Bhopal	CP2	CA2	698	18.83	2,698	58,230
Kochi	CP2	CA1	126	21.18	16,809	48,125
Patna	CP2	CA1	235	20.47	8,720	45,230
Varanasi	CP2	CA3	1,550	14.35	926	40,560
Nagpur	CP2	CA1	218	24.98	11,458	81,225
Jaipur	CP2	CA1	112	30.46	27,198	95,904
Kanpur	CP2	CA3	3,029	29.20	964	98,000
Surat	CP3	CA2	327	45.85	14,023	52,030
Pune	CP3	CA2	710	50.50	7,113	22,178
Ahmadabad	CP3	CA2	464	63.52	13,690	75,115
Hyderabad	CP3	CA2	650	77.49	11,922	77,277
Chennai	CP3	CA2	426	86.96	20,413	21,885
Bangalore	CP3	CA2	741	84.99	11,470	1,10,400
Kolkata	CP3	CA3	1,887	141.13	7,480	26,710
Delhi	CP3	CA3	1,484	163.15	10,994	1,35,820
Mumbai	CP3	CA3	4,355	184.14	4,228	4,30,548

Table 5.1b: Data for the Simple Linear Regression (Contd.)

City Name	City Buses (Govt.+Pvt.)	Reg Veh (Nos)	Trip Rate (all modes)	Trip Rate (Motorised)
Gangtok	-	3,977	0.87	0.39
Panaji	8	1,26,777	0.78	0.47
Shimla	16	1,39,300	0.79	0.33
Raipur	-	5,79,000	0.94	0.38
Bhuvaneswar	32	4,22,994	0.98	0.48
Hubli Dharwad	170	3,12,552	0.93	0.54
Guwahati	62	3,98,000	0.99	0.58
Amritsar	-	6,92,791	1.10	0.53
Madurai	609	6,80,000	1.15	0.56

City Name	City Buses (Govt.+Pvt.)	Reg Veh (Nos)	Trip Rate (all modes)	Trip Rate (Motorised)
Agra	20	4,75,700	1.07	0.57
Bhopal	240	8,29,000	1.15	0.65
Kochi	350	3,03,436	1.22	0.98
Patna	0	4,84,366	1.23	0.53
Varnasi	0	5,88,000	1.13	0.67
Nagpur	241	12,36,174	1.30	0.64
Jaipur	327	7,09,638	1.25	0.78
Kanpur	176	5,77,896	1.21	0.62
Surat	106	18,00,641	1.30	0.75
Pune	824	22,67,000	1.31	0.88
Ahmadabad	886	9,29,757	1.41	0.91
Hyderabad	2,546	33,87,000	1.44	1.01
Chennai	2,816	37,67,000	1.51	1.02
Bangalore	4,185	41,56,000	1.42	0.97
Kolkata	4,256	4,96,000	1.58	1.04
Delhi	6,906	82,93,167	1.58	1.1
Mumbai	3,430	73,50,000	1.68	1.13

The simple linear regression equation is as follows

$$Y=bX_1 + a \qquad (5.1)$$

Where,

Y= Predicting variable, a = constant,

X_1= predictor variable,

b = regression coefficient

Linear regression models were formed for Trip Rate with various independent variables like City Area, Population, Registered Vehicles, Per Capita Income and City buses. Results of regression analysis are summarised in Table 5.2.

Table 5.2: Models for Trip Rate with Single Independent Variable

		Coefficient (t-Stat)	Models of Trip Rate for Various City Categories						
			All Cities	CP 1	CP 2	CP 3	CA 1	CA 2	CA 3
M 1	V	City Area (sqkm)	--	0.0005 (2.80)	--	7.97×10^{-5} (3.49)	--	--	--
		Intercept	--	0.80 (21.32)	--	1.37 (34.96)	--	--	--
	F	Sample Size	--	6	--	9	--	--	--
		R-Square	--	0.66	--	0.63	--	--	--
		F-test(Table)	--	7.8(7.7)	--	12.2(5.6)	--	--	--
M 2	V	Population (In Lakhs)	0.0042 (8.91)	0.0188 (3.98)	0.0118 (3.68)	0.0024 (8.41)	0.0181 (9.29)	0.0057 (8.81)	0.0032 (18.31)
		Intercept	1.01 (32.00)	0.79 (25.04)	0.92 (14.12)	1.22 (38.60)	0.79 (24.67)	1.00 (25.24)	1.08 (53.01)
	F	Sample Size	26	6	11	9	12	8	6
		R-Square	0.76	0.79	0.60	0.91	0.89	0.92	0.98
		F-test(Table)	79(4.3)	16(7.7)	13(5.1)	70.8(5.6)	86.4(4.6)	77.7(6)	335(7.7)
M 3	V	Registered Veh (Nos.)	8×10^{-8} (5.11)	4.4×10^{-7} (2.82)	--	--	4.23×10^{-7} (3.63)	9.4×10^{-8} (3.01)	5.02×10^{-8} (2.08)
		Intercept	1.07 (25.19)	0.78 (17.42)	--	--	0.85 (13.23)	1.10 (13.78)	1.23 (11.21)
	F	Sample Size	26	6	--	--	12	8	6
		R-Square	0.52	0.64	--	--	0.57	0.60	0.52
		F-test(Table)	26(4.3)	7.4(7)	--	--	13(4.9)	9.1(5.9)	4.3(4.2)
M 4	V	Per Capita Income (Rs.)	--	--	--	6.43×10^{-7} (2.21)	6.53×10^{-6} (3.67)	--	--
		Intercept	--	--	--	1.40 (30.14)	0.73 (8.04)	--	--
	F	Sample Size	--	--	--	9	12	--	--
		R-Square	--	--	--	0.41	0.57	--	--
		F-test(Table)	--	--	--	4.9(4.8)	13.5(4.9)	--	--
M 5	V	City Buses (Nos.)	0.0001 (5.61)	--	--	4.35×10^{-5} (2.75)	--	8.07×10^{-5} (2.47)	7.83×10^{-5} (3.41)
		Intercept	1.09 (28.65)	--	--	1.34 (24.26)	--	1.19 (17.94)	1.18 (14.40)
	F	Sample Size	26	--	--	9	--	8	6
		R-Square	0.57	--	--	0.52	--	0.50	0.74
		F-test(Table)	31.5(4)	--	--	7.6(5.5)	--	6.1(5.9)	11.7(7.7)

Note: (1) M 1 stands for model 1, V stands for Variable, F stands for model features

(2) Reading M 1 for CP1 is (from above table): *Trip Rate = 0.0005*City Area+0.80*

(2.80) (21.32)

(3) Values of t- statistic and F-table are presented in parenthesis.

Variable City Area is found to be logical and significant for CP1 and CP3. Population of the city is logical and significant for all categories of cities. Variable Registered vehicles is insignificant for CP2 and CP3. Per Capita Income plays a vital role in CP3 and CA1. Number of city buses is insignificant for CP1, CP2 and CA1. Motorised trip rate models were also formed using simple linear regression technique. The details are presented in table 5.3.

Table 5.3: Models for Motorized Trip Rate with Single Independent Variable

		Coefficient (t-Stat)	**Models of Motorized Trip Rate for Various City Categories**						
			All Cities	**CP 1**	**CP 2**	**CP 3**	**CA 1**	**CA 2**	**CA 3**
M 6	V	Population (In Lakhs)	0.0040 (7.90)	0.0174 (2.86)	--	0.0020 (4.77)	0.0137 (3.45)	0.0063 (9.28)	0.0033 (11.37)
		Intercept	0.53 (15.57)	0.371 (9.14)	--	0.77 (16.41)	0.37 (5.71)	0.48 (11.73)	0.55 (16.17)
	F	Sample Size	26	6	--	9	12	8	6
		R-Square	0.72	0.67	--	0.76	0.54	0.93	0.97
		F-test(Table)	62.5(4)	8(7.7)	--	22.8(5.6)	11.9(4.9)	86.2(6)	129(7.7)
M 7	V	Registered Veh. (Nos)	8.0×10^{-8} (5.02)	4×10^{-7} (2.13)	--	2.86×10^{-8} (2.30)	--	1.09×10^{-7} (3.51)	5.4×10^{-8} (2.26)
		Intercept	0.58 (13.79)	0.37 (7.06)	--	0.87 (15.95)	--	0.59 (7.40)	0.68 (6.32)
	F	Sample Size	26	6	--	9	--	8	6
		R-Square	0.51	0.53	--	0.43	--	0.67	0.56
		F-test(Table)	25(4.3)	4.6(7.7)	--	5.3(5.6)	--	12.3(6)	5.1(4.7)
M 8	V	Per Capita Income (Rs.)	--	--	--	--	4.31×10^{-6} (1.90)	--	--
		Intercept	--	--	--	--	0.35 (3.07)	--	--
	F	Sample Size	--	--	--	--	12	--	--
		R-Square	--	--	--	--	0.26	--	--
		F-test(Table)	--	--	--	--	3.6(2.9)	--	--
M 9	V	City Buses (Nos.)	0.0001 (5.95)	--	0.0003 (1.84)	4.45×10^{-5} (3.55)	0.0005 (2.29)	9.58×10^{-5} (2.92)	8.4×10^{-5} (4.06)
		Intercept	0.59 (16.51)	--	0.56 (9.40)	0.85 (19.38)	0.48 (8.53)	0.69 (10.37)	0.64 (8.58)
	F	Sample Size	26	--	11	9	12	8	6
		R-Square	0.59	--	0.20	0.64	0.34	0.58	0.80
		F-test(Table)	35.5(4.2)	--	2.2(2.1)	12.6(6.6)	5.3(5)	8.6(6)	16.5(7.7)

Note: (1) M 6 stands for model 6, V stands for Variable, F stands for model features

*(2) Reading M 6 for CP1 is(from above table): Motorized Trip Rate = 0.0174*Population +0.371*

(2.86) (9.14)

(3) Values of t- statistic and F-Table are given in parenthesis.

Population of the city is logical and significant for all Motorized Trip Rate models of various city categories except for CP2. Registered Vehicles of the city plays an insignificant role for CP2 and CA1 Motorized Trip Rate models. Per Capita Income is found to be logical for CA1 Motorized Trip Rate model. Number of City Buses is logical and significant for all these categories of models apart from CP1.

Average Trip length (km) was also modelled with various variables like city area, population, population density, registered vehicles, per capita income and city buses. Summary of models developed are presented in Table 5.4.

Table 5.4: Models for Trip Length (km) with Single Independent Variable

		Coefficient (t-Stat)	**Models of Trip Length for Various City Categories**						
			All Cities	**CP 1**	**CP 2**	**CP 3**	**CA 1**	**CA 2**	**CA 3**
M 10	V	City Area (sqkm)	0.0014 (3.42)	0.0043 (2.52)	--	0.0014 (3.50)	--	--	--
		Intercept	5.37 (9.53)	3.20 (8.85)	--	7.68 (10.68)	--	--	--
	F	Sample Size	26	6	--	9	--	--	--
		R-Square	0.32	0.61	--	0.63	--	--	--
		F-test(Table)	11(4.3)	6.4(7.7)	--	12.3(5.6)	--	--	--
M 11	V	Population (In Lakhs)	0.0513 (17.24)	0.1857 (12.11)	0.0950 (3.26)	0.0448 (9.51)	0.1238 (7.74)	0.0637 (9.58)	0.0439 (16.53)
		Intercept	4.29 (21.68)	2.90 (28.43)	3.75 (6.29)	5.00 (9.59)	3.15 (11.98)	3.78 (9.31)	5.05 (16.30)
	F	Sample Size	26	6	11	9	12	8	6
		R-Square	0.92	0.97	0.54	0.92	0.85	0.93	0.98
		F-test(Table)	297(4)	147(7.7)	10.7(5)	90.6(5.6)	60(4.9)	91.9(6)	273(7.7)
M 12	V	Pop Density (Persons /Sqkm)	--	--	--	--	0.0001 (4.09)	0.0002 (2.82)	0.0006 (2.71)
		Intercept	--	--	--	--	3.61 (9.40)	4.79 (4.80)	6.25 (4.44)
	F	Sample Size	--	--	--	--	12	8	6
		R-Square	--	--	--	--	0.62	0.57	0.65
		F-test(Table)	--	--	--	--	16.7(5)	8(6)	7.4(5.7)
M 13	V	Registered Veh (Nos.)	--	4.59×10^{-6} (5.71)	--	5.47×10^{-7} (2.13)	2.69×10^{-6} (3.01)	1.28×10^{-6} (7.83)	6.76×10^{-7} (2.03)
		Intercept	--	2.82 (12.57)	--	7.50 (6.63)	3.62 (7.33)	4.45 (10.57)	7.00 (4.62)
	F	Sample Size	--	6	--	9	12	8	6
		R-Square	--	0.89	--	0.39	0.47	0.91	0.51
		F-test(Table)	--	32.7(7.7)	--	4.5(3.6)	9(5)	61.3(6)	4.12(3.7)
M 14	V	Per Capita Income (Rs.)	--	--	--	1.14×10^{-5} (2.09)	4.42×10^{-5} (3.44)	--	--
		Intercept	--	--	--	8.27 (9.48)	2.75 (4.18)	--	--

		Coefficient (t-Stat)	Models of Trip Length for Various City Categories						
			All Cities	**CP 1**	**CP 2**	**CP 3**	**CA 1**	**CA 2**	**CA 3**
	F	Sample Size	--	--	--	9	12	--	--
	F	R-Square	--	--	--	0.38	0.54	--	--
	F	F-test(Table)	--	--	--	4.4(3.6)	11.9(5)	--	--
M 15	V	City Buses (Nos.)	0.0013 (9.05)	0.0087 (1.85)	0.0024 (2.08)	0.0009 (3.87)	0.0048 (3.49)	0.0011 (5.73)	0.0010 (3.53)
M 15	V	Intercept	5.11 (16.88)	3.48 (9.77)	5.17 (17.06)	6.84 (8.26)	4.11 (12.24)	5.58 (13.53)	6.38 (5.81)
M 15	F	Sample Size	26	6	11	9	12	8	6
M 15	F	R-Square	0.77	0.46	0.32	0.68	0.55	0.84	0.76
M 15	F	F-test(Table)	82(4.2)	3.4(2.7)	4.3(3.1)	15(5.6)	12.2(5.6)	32.8(6)	12.5(7.7)

Note: (1) M 10 stands for model 10, V stands for Variable, F stands for model features

(2) Reading M 10 for CP1 is (from above table): *Trip Length = 0.0043*City Area+3.20*

(2.52) (8.85)

(3) Values of t- statistic and F-Table are given in parenthesis.

For Trip Length models, Population and number of city buses are logical and significant for all categories of cities. City Area is insignificant for CP2, CA1, CA2 and CA3. Population density is significant for CA1, CA2 and CA3 categories of cities. Registered Vehicles is found to be vital for CP1, CP3, CA1, CA2 and CA3 categories of cities. Per Capita Income is significant for CP3 and CA1 categories.

5.4. Multiple Linear Regression Models

Trip rate interaction with various socio-economic and land use variables were worked out. Parameters are analyzed using multiple regression analysis. The following methodology is adopted:

1. Parameters like trip rate, population, population density, area, per capita income, registered vehicles and land use share were considered for these cities. Data is presented in Table 5.5.
2. Variation of those parameters were studied on the trip rate for both motorized and all modes separately.
3. Correlation matrix between various variables were worked out and presented in Table 5.6 (for All Cities) & Annexure (For Category wise).
4. After observing the matrix, the combination of variables for the models was selected.
5. Multiple linear regression analysis is carried out for the better combination and forming healthy relationships.

Table 5.5a: Data for Multiple Regression Models

City Name	Population Category	Area Category	Area(sq km)	Population (in lakhs)	Population Density (persons/Sqkm)	Industrial Area (%)
Gangtok	CP1	CA1	35	1.00	2,865	2.0
Panaji	CP1	CA1	29	1.45	4,999	0.0
Shimla	CP1	CA1	76	1.72	2,261	0.6
Raipur	CP2	CA1	226	11.23	4,967	5.7
Bhuvaneswar	CP1	CA2	419	8.82	2,105	1.7
Hubli Dharwad	CP1	CA1	202	9.44	4,665	5.0
Guwahati	CP1	CA1	216	9.69	4,484	2.8
Amritsar	CP2	CA3	2,683	11.84	441	3.1
Madurai	CP2	CA1	248	14.62	5,897	0.8
Agra	CP2	CA1	188	17.46	9,270	6.8
Bhopal	CP2	CA2	698	18.83	2,698	9.0
Kochi	CP2	CA1	126	21.18	16,809	5.7
Patna	CP2	CA1	235	20.47	8,720	1.7
Varnasi	CP2	CA3	1,550	14.35	926	3.6
Nagpur	CP2	CA1	218	24.98	11,458	2.0
Jaipur	CP2	CA1	112	30.46	27,198	3.7
Kanpur	CP2	CA3	3,029	29.20	964	6.9
Surat	CP3	CA2	327	45.85	14,023	5.0
Pune	CP3	CA2	710	50.50	7,113	4.0
Ahmadabad	CP3	CA2	464	63.52	13,690	15.3
Hyderabad	CP3	CA2	650	77.49	11,922	1.3
Chennai	CP3	CA2	426	86.96	20,413	3.1
Bangalore	CP3	CA2	741	84.99	11,470	6.8
Kolkata	CP3	CA3	1,887	141.13	7,480	3.3
Delhi	CP3	CA3	1,484	163.15	10,994	6.0
Mumbai	CP3	CA3	4,355	184.14	4,228	6.0

Table 5.5b: Data for Multiple Regression Models (Contd.)

City Name	City Buses (Govt.+Pvt.)	Reg Veh (Nos)	Trip Rate (all modes)	Trip Rate (Motorised)
Gangtok	0	3,977	0.87	0.39
Panaji	8	1,26,777	0.78	0.47
Shimla	16	1,39,300	0.79	0.33
Raipur	0	5,79,000	0.94	0.38
Bhubaneswar	32	4,22,994	0.98	0.48
Hubli Dharwad	170	3,12,552	0.93	0.54
Guwahati	62	3,98,000	0.99	0.58
Amritsar	0	6,92,791	1.10	0.53
Madurai	609	6,80,000	1.15	0.56
Agra	20	4,75,700	1.07	0.57
Bhopal	240	8,29,000	1.15	0.65

City Name	City Buses (Govt.+Pvt.)	Reg Veh (Nos)	Trip Rate (all modes)	Trip Rate (Motorised)
Kochi	350	3,03,436	1.22	0.98
Patna	0	4,84,366	1.23	0.53
Varanasi	0	5,88,000	1.13	0.67
Nagpur	241	12,36,174	1.30	0.64
Jaipur	327	7,09,638	1.25	0.78
Kanpur	176	5,77,896	1.21	0.62
Surat	106	18,00,641	1.30	0.75
Pune	824	22,67,000	1.31	0.88
Ahmadabad	886	9,29,757	1.41	0.91
Hyderabad	2,546	33,87,000	1.44	1.01
Chennai	2,816	37,67,000	1.51	1.02
Bangalore	4,185	41,56,000	1.42	0.97
Kolkata	4,256	4,96,000	1.58	1.04
Delhi	6,906	82,93,167	1.58	1.10
Mumbai	3,430	73,50,000	1.68	1.13

Table 5.6a: Correlation Matrix for the Data Considered-All Cities

	A	B	C	D	E	F	G	H	I	J	K	L
A	1.00											
B	0.58	1.00										
C	-0.34	0.24	1.00									
D	0.79	0.55	-0.10	1.00								
E	0.39	0.25	-0.16	0.36	1.00							
F	-0.38	-0.23	0.18	-0.36	-0.99	1.00						
G	0.37	0.90	0.24	0.32	0.09	-0.08	1.00					
H	0.41	0.58	0.05	0.21	0.23	-0.22	0.36	1.00				
I	-0.28	-0.22	-0.04	-0.17	0.27	-0.27	-0.13	-0.32	1.00			
J	0.47	0.85	0.21	0.56	0.24	-0.23	0.83	0.24	-0.15	1.00		
K	0.08	-0.07	-0.14	0.12	0.26	-0.29	-0.04	0.14	-0.11	-0.03	1.00	
L	-0.07	0.00	-0.07	-0.07	0.07	-0.05	0.09	-0.26	0.36	0.03	-0.06	1.00
M	0.19	0.25	0.16	0.28	0.11	-0.08	0.14	0.18	-0.33	0.17	0.23	-0.21
N	-0.17	-0.08	-0.14	-0.10	-0.43	0.43	0.03	-0.35	-0.15	0.08	-0.16	0.58
O	0.13	0.20	-0.22	0.10	-0.18	0.20	0.23	-0.12	-0.19	0.22	-0.07	0.22
P	0.12	0.02	-0.45	0.20	-0.16	0.12	0.08	-0.05	-0.13	0.14	0.30	0.00
Q	-0.04	0.03	0.20	-0.29	-0.32	0.32	0.05	0.18	-0.22	-0.13	-0.49	-0.34
R	0.22	0.14	-0.03	0.33	-0.15	0.14	0.02	0.16	-0.13	0.15	-0.30	-0.28
S	-0.07	-0.25	-0.30	-0.17	0.09	-0.08	-0.20	-0.23	0.13	-0.20	-0.35	-0.11
T	-0.16	-0.08	0.30	0.00	0.50	-0.48	-0.18	-0.11	0.60	-0.08	-0.22	0.05
U	0.49	0.88	0.46	0.46	0.13	-0.09	0.75	0.63	-0.43	0.72	-0.06	-0.06
V	0.38	0.85	0.52	0.37	0.05	-0.02	0.77	0.52	-0.29	0.72	-0.08	0.05

Note: A- Area(sqkm); B-Population (In Lakhs); C- Population Density(persons/sqkm); D-PerCapita Income(Rs); E- Male%; F- Female%; G-City Buses(Nos); H- Road Safety Index; I- Road Density ; J- Registered Vehicles; K- Residential(%); L- Commercial(%); M- Industrial(%); N- Public & Semi Public; O- Recreational(%); P- Transport(%); Q- Agricultural(%); R- Water bodies(%); S- Open Spaces(%); T- Others(%); U- Trip Rate; V- Motorized Trip Rate

Table 5.6b: Correlation Matrix for the Data Considered (Contd..)

	M	N	O	P	Q	R	S	T	U	V
M	1.00									
N	-0.15	1.00								
O	0.13	0.58	1.00							
P	0.14	0.43	0.17	1.00						
Q	-0.35	-0.32	-0.28	-0.48	1.00					
R	-0.09	-0.20	-0.23	-0.20	0.28	1.00				
S	-0.24	-0.05	-0.17	-0.09	0.14	0.20	1.00			
T	0.07	-0.39	-0.32	-0.36	-0.24	-0.16	0.10	1.00		
U	0.34	-0.13	0.06	-0.16	0.19	0.13	-0.33	-0.11	1.00	
V	0.35	-0.09	0.04	-0.17	0.08	0.18	-0.35	-0.01	0.92	1.00

In the multivariable regression model, the dependent variable is pronounced as a linear function of the independent variables X_i, as follows: $Y = a + b_1 \times X_1 + b_2 \times X_2 + \ldots + b_n \times X_n$,

Where, Y = dependent variable, X_i = independent variables, a = constant (y-intercept), b_i= regression coefficient of the variable X_i.

Multiple linear regression models for trip rate and motorised trip rate are given in Tables 5.7 and 5.8, respectively.

Table 5.7: Multiple Linear Regression Models for Trip Rate for Various City Categories

		Coefficient (t-Stat)	**Models of Trip Rate for Various City Categories**						
			All Cities	**CP 1**	**CP 2**	**CP 3**	**CA 1**	**CA 2**	**CA 3**
M16	V	City Area (sqkm)	--	0.000151 (0.57)	--	6.1×10^{-5} (3.44)	--	--	--
		Population (In Lakhs)	0.0041 (23.36)	0.0146 (1.60)	0.0108 (3.19)	--	0.0169 (5.43)	--	--
		Pop Density (Persons / sqkm)	--	--	--	--	--	1.95×10^{-5} (3.39)	3.42×10^{-5} (1.36)
		Reg. Veh (In thousands)	--	--	--	--	5×10^{-5} (0.54)	--	2.47×10^{-5} (0.86)
		City Buses	--	--	0.000103 (0.92)	2.94×10^{-5} (2.74)	--	3.98×10^{-5} (1.72)	--
		Industrial Area (%)	0.00998 (1.29)	--	--	--	--	--	--
		Intercept	0.980 (23.36)	0.787 (22.68)	0.928 (14.00)	1.31 (36.31)	0.79 (22.82)	1.053 (18.04)	1.163 (10.50)
	F	Sample Size	26	6	11	9	12	8	6
		R-Square	0.78	0.81	0.63	0.83	0.89	0.85	0.70
		F-test(Table)	41.7(3.4)	6.8(5.5)	7.1(4.5)	15.6(5.1)	40.3(4.3)	14.2(5.8)	3.5(3.5)

Note: (1) M 16 stands for model 10, V stands for Variable, F stands for model features

*(2)M 17 for All cities is: Trip Rate = 0.0041*Population+0.0099*Industrial Area +0.98*

(23.36) (1.29) (23.36)

(3) Values of t- statistic and F-Table are given in parenthesis.

In developing Trip Rate models, it is found that Population and Industrial Area (%) are logical and significant for combined cities data. City Area and Population are logical for CP1 City category. Population is significant and City Buses are logical for City category CP2. City Area and City buses are logical and significant for CP3. Population is significant and registered vehicles is logical for city category CA1. Population density and city buses are logical and significant for CA2 category. Population density and registered vehicles are logical for city category of CA3.

Table 5.8: Multiple Linear Regression Models for Motorised Trip Rate for Various Cities

		Coefficient (t-Stat)	**Models of Motorised Trip Rate for Various City Categories**						
			All Cities	**CP 1**	**CP 2**	**CP 3**	**CA 1**	**CA 2**	**CA 3**
M17	V	City Area (sqkm)	--	--	--	--	--	--	--
		Population (In Lakhs)	0.00389 (7.43)	--	--	0.00148 (2.18)	--	--	0.0029 (4.27)
		Population Density (persons/sqkm)	--	--	9.01x10^{-6} (1.58)	--	1.66x10^{-5} (3.20)	1.6x10^{-5} (2.09)	--
		Reg. Veh (In thousands)	--	3.18x10^{-4} (1.46)	--	--	--	--	--
		City Buses (Nos.)	--	--	0.000204 (0.88)	1.69x10^{-5} (1.04)	0.000267 (2.41)	6.23x10^{-5} (2.02)	1.01x10^{-5} (0.51)
		Industrial Area (%)	0.011 (1.33)	0.0177 (0.85)	--	--	--	--	--
		Intercept	0.492 (10.93)	0.354 (6.13)	0.518 (8.16)	0.782 (16.51)	0.378 (7.32)	0.576 (7.40)	0.552 (14.39)
	F	Sample Size	26	6	11	9	12	8	6
		R-Square	0.74	0.62	0.58	0.80	0.69	0.78	0.97
		F-test(Table)	33.1(3.4)	2.5(1.5)	2.5(2.4)	12.1(5.1)	10.2(4.3)	8.9(5.8)	52.9(9.5)

Note: (1) M 17 stands for model 17, V stands for Variable, F stands for model features

*(2)M 17 for All cities is: Motorized Trip Rate = 0.0039*Population+0.01*Industrial Area(%)+0.49*

(7.43) (1.33) (10.9)

(3) Values of t-statistic and F-Table are given in parenthesis.

Motorized Trip Rate models shows that Population is significant and Industrial Area (%) is logical for combined cities data. Registered vehicles and Industrial Area (%) are logical for city category CP1. Population density and number of city buses are logical for city category

CP2. Population is significant and number of city buses is logical for city category CP3. It is observed that Population density, number of city buses is logical and significant for CA1 and CA2 categories. Population is significant and city buses found to be logical for CA3 category.

5.5. Models Validation

A separate data set is considered for the validation of formulated models. Trip rate is estimated based on the models developed. The difference between predicted and actual trip rates is the error in prediction. From these errors, mean square error (MSE) is calculated. Validation data is presented in Table 5.9. Mean Square Error (MSE) is calculated for various models and tabulated in Table 5.10.

Table 5.9a: Data for Validation

	Area (sq km)	**Populatio n (2011)**	**Population (in lakhs)**	**Population density(persons/ sqkm)**	**Trip length (kms)**	**Per capita income(Rs)**
Pondicherry	474	12,47,953	12.47953	3,232	3.7	74,720
Bikenar	270	6,44,406	6.44406	2,386	3.5	50,775
Chandigarh	114	10,55,450	10.5545	9,300	5.1	26,710
Trivandrum	250	33,01,427	33.01427	6,700	5.6	1,02,000

Table 5.9b: Data for Validation (Contd.)

	Trip Rate(all modes)	**Trip Rate (Motorised)**	**City Buses (Govt.+Pvt.)**
Pondicherry	0.97	0.41	49
Bikenar	0.81	0.28	0
Chandigarh	1.19	0.71	209
Trivandrum	1.03	0.57	242

Table 5.10: Models for Various City Categories - Validation (MSE)

Model Type	**Model ID**	**Models for Various City Categories-Validation(MSE)**						
		All Cities	**CP 1**	**CP 2**	**CP 3**	**CA 1**	**CA 2**	**CA 3**
Trip Rate (TR)	M1	--	0.02	--	--	--	--	--
	M2	0.00	0.01	0.06	--	0.06	0.01	--
	M3	--	--	--	--	--	--	--
	M4	--	--	--	--	0.09	--	--
	M5	0.03	--	--	--	--	0.05	--
Motorized Trip Rate (MTR)	M6	0.03	0.04	--	--	0.04	0.02	--
	M7	--	--	--	--	--	--	--
	M8	--	--	--	--	--	0.06	--
	M9	0.04		0.01		0.02	0.08	--
Trip Length (TL)	M10	2.67	0.74	--	--	--	--	--
	M11	0.75	0.36	1.10	--	1.10	0.76	--
	M12	--	--	--	--	0.70	3.12	--

Model Type	Model ID	Models for Various City Categories-Validation(MSE)						
		All Cities	CP 1	CP 2	CP 3	CA 1	CA 2	CA 3
	M13	--	--	--	--	--	--	--
	M14	--	--	--	--	2.12	--	--
	M15	1.22	0.00	0.96		0.16	3.74	
TR-MLR	M16	--	0.01	0.03	--	--	0.02	--
MTR-MLR	M17	--	--	0.01	--	0.01	0.05	--

5.6. Principal Component Analysis

Principal component analysis (PCA) is a technique helpful in finding similar kinds of patterns in data. When a data set with high dimensionality is considered, it becomes difficult to represent the entire data as a 2-D representation. It deals with more number of dimensions and reduces them to a fewer dimension which helps in plotting a graph which explains more information compared to the data represented directly on the 2-D plot. It also brings out the similarities in the data which will be helpful in a classification task.

PCA Methodology is presented below.

- Data for which the dimensions needed to be reduced is selected.
- Mean of each dimension is calculated and subtracted from the original value. This way the data is adjusted which is easy to represent the data pattern on a plot.
- So the data set whose mean is zero is formed.
- Now the adjusted data is used to calculate covariance matrix. The covariance matrix obtained is a square matrix which is based on the dimensionality of the adjusted data. For example, if the adjusted data has five dimensions then covariance matrix would be a 5 x 5 matrix.
- Non-diagonal elements of the covariance matrix represent the behaviour of the variables.
- This covariance matrix is used further to calculate Eigen vectors and Eigen values.
- It is important to make sure the Eigenvector obtained is a unit vector.

- Eigenvector with the highest Eigen value is then arranged in descending order.
- Now a feature vector is selected which is nothing but Eigenvectors which are selected for representing the entire data.
- These Eigenvectors are nothing but the principal components (PCs) which become the major axes and reduce the dimensionality problem

Total of 20 (Socio-economic and land use as given in Table 4.4) variables were considered to find the principal components (PCs). Out of 20, ten variables are socio-economic related and ten variables are land-use related. All the variables are processed to find Principal Components. From 20 principal components, 10 components are shown in scree plot (Figure 5.1) as those contribute to around 94%. The scree plot (Figure 5.1) is a combination plot of the variance of each Eigen value of principal component and cumulative variance against each principal component. This shows how much information each principal component carries out. Maximum information is explained by the first three to five principal components. So, for further analysis, first five principal components are considered. This input data is explaining almost 70% of the data.

Principal components 1 and 2 are considered to find the pattern similarities between parameters of socio-economic and land use of cities. So, plots of eigenvalues of variables are plotted against first principal component and second principal component. The plots shown in Figures 5.2 and 5.3 consist of the correlation between observations and variables, i.e., correlation between a city and its parameters. The dots represent the relative positions of cities with principal component one and two.

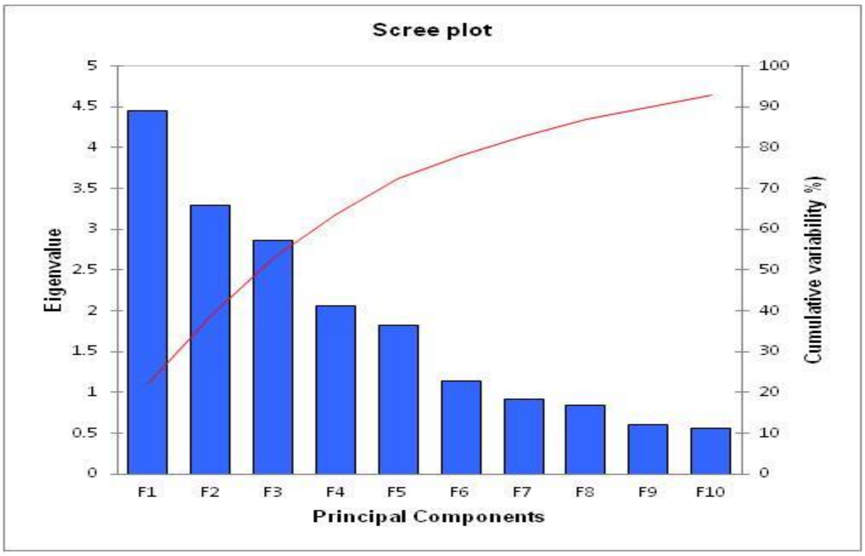


Figure 5.1: Plot showing the significance of 10 Principal Components

Figure 5.2 is also called as correlation circle. This chart exhibits between variables. Horizontal axis is first PC dimension contains 22.27% of initial information. Vertical axis is second PC dimension contains 16.46% of initial information. Here, things should be interpreted in terms of angles between the variables. Acute angle represents positive relationship. Right angle represents no relation. Obtuse angle represents negative relation. Higher vector length represents that this variable is represented in that PC dimension. Shorter vector length represents that this variable is likely to represent in other PC dimension. Figure 5.3 is also called as observation chart. This chart helps to relate individuals to variables and to one another.

Lines represent the position of the parameter on principal component one and two. For clear understanding, the position of cities is labelled and plotted.

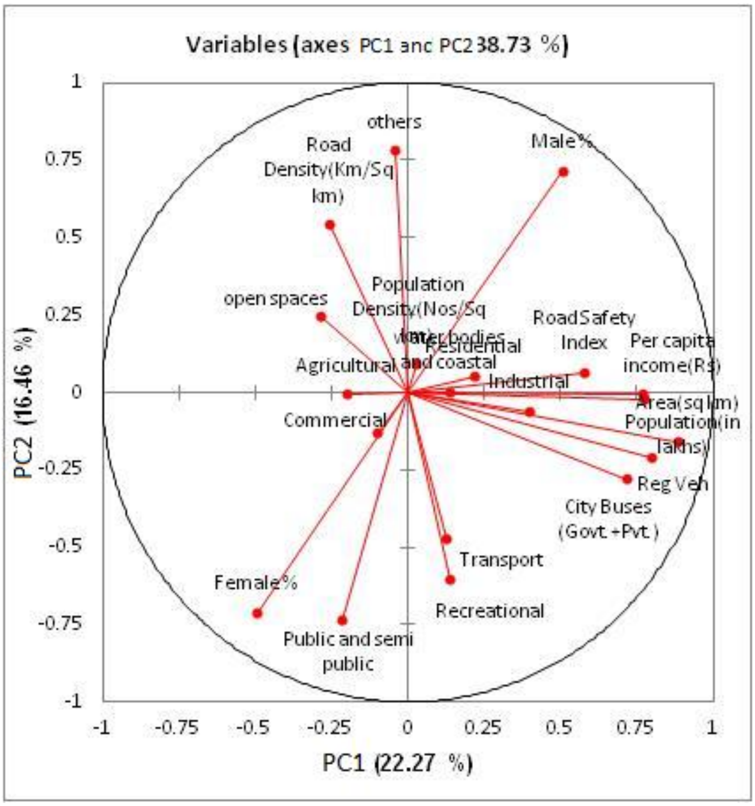


Figure 5.2: Scatter plot of parameters on PC1 and PC2

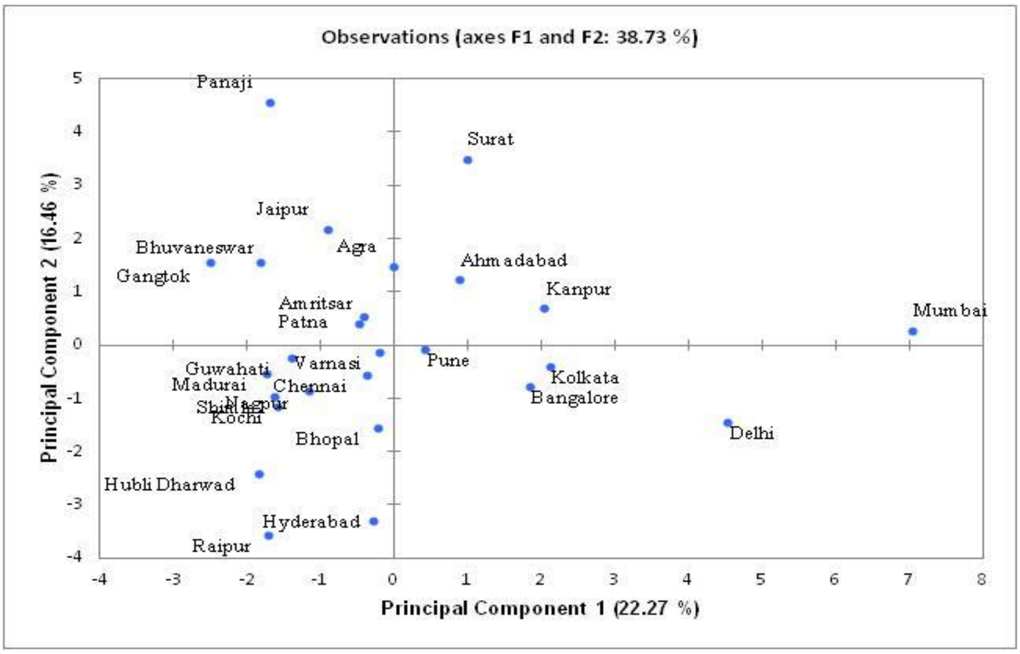


Figure 5.3: Scatter plot of cities on PC1 and PC2

Correlation value greater than 0.5 is considered as significant variables. Area (sq.km), Population (In Lakhs), Per Capita Income, city buses, Registered Vehicles, are grouped under component 1. The same is also evident from Figure 5.2. These variables are positive towards component 1. It indicates that each parameter changes with change in one or two parameters. It also concludes that these parameters are interlinked. Variables that are correlated with component 2 are Male (%), female (%) and Public area (%). Details are given in Table 5.11. Out of 100% of total data, Principal components 1 through 5 are contributing 22.2%, 16.4%, 14.3%, 10.3% and 9.1% respectively.

Table 5.11: Highly correlated parameters for Principal Components

Principal Component	Variability Explained (%)	Variables Correlated
PC1	22.27	Area, Population, Per Capita Income, City Buses, Registered Vehicles
PC2	16.46	Male (%), Female (%) and Public Area (%)
PC3	14.32	Transport Area (%), Agricultural Area (%)
PC4	10.33	Commercial Area (%)
PC5	9.12	Population Density

5.7 TRIP RATE PREDICTION MODELS USING PRINCIPAL COMPONENTS

Regression models were developed for all cities data with principal components. Models with all principal components of Trip Rate and Motorized Trip Rate are presented in Tables 5.12 to 5.13, respectively.

Table 5.12: Models for Trip Rate with All Principal Components

		Coefficient (t-Stat)	Models of Trip Rate for Various City Categories						
			All Cities	**CP 1**	**CP 2**	**CP 3**	**CA 1**	**CA 2**	**CA 3**
M 18	V	PC 1	0.088 (10.7)	0.018 (65535)	-0.013 (-1.0.3)	0.034 (4.29)	-0.05 (-6.28)	0.041 (6.10)	-0.05 (65535)
		PC 2	-0.023 (-2.38)	0.018 (65535)	0.026 (1.71)	-0.013 (-1.49)	-0.04 (-3.61)	0.015 (1.81)	0.046 (65535)
		PC3	0.056 (5.50)	0.021 (65535)	0.0046 (0.25)	-0.04 (-3.56)	0.025 (1.84)	0.057 (6.82)	-0.075 (65535)
		PC 4	0.044 (3.69)	-0.013 (65535)	0.007 (0.34)	-0.014 (-1.04)	-0.009 (-0.62)	-0.018 (-1.49)	-0.037 (65535)
		PC 5	-0.03 (-2.82)	-0.02 (65535)	0.008 (0.39)	-0.0255 (-1.67)	$-6.7X10^{-5}$ (-0.003)	0.017 (1.30)	-0.009 (65535)
		Intercept	1.204 (69.0)	0.89 (65535)	1.16 (37.1)	1.47 (77.20)	1.04 (46.5)	1.31 (77.67)	1.38 (65535)
	F	Sample Size	26	6	11	9	12	8	6
		R-Square	0.89	1.00	0.46	0.92	0.90	0.98	1.00
		F-test(Table)	34(3)	--	0.8(4.4)	7.45(5.4)	11.2(4)	18(6.6)	--

From Trip Rate Models, PC1, PC3, PC4 are significant for combined cities data. PC1, PC2 and PC3 variables are significant for cities of category CP1. For city category of CP2, PC1 is negatively correlated with Trip Rate and PC2 is positively correlated. For city category of CP3, PC1 is positively correlated with Trip Rate. As the principal component has the properties of various input variables, the combined effect of these variables would be leading to either positive or negative correlation.

It is found that PC3 positively correlated with Trip Rate for city category of CA1. For city category of CA2, PC1, PC3 are positively and significantly correlated. PC1, PC3, PC4, PC5 are observed to be negatively and PC2 positively correlated with Trip Rate for city category of CA3.

Table 5.13: Models for Motorized Trip Rate with All Principal Components

		Coefficient (t-Stat)	Models of Motorized Trip Rate for Various City Categories						
			All Cities	**CP 1**	**CP 2**	**CP 3**	**CA 1**	**CA 2**	**CA 3**
M 20	V	PC 1	0.078 (8.07)	0.009 (65535)	-0.026 (-1.34)	0.03 (4.14)	-0.037 (-2.78)	0.054 (5.00)	-0.05 (65535)
		PC 2	-0.02 (-1.94)	0.005 (65535)	0.027 (1.17)	-0.03 (-3.49)	-0.043 (-2.49)	0.012 (0.93)	0.06 (65535)
		PC3	0.048 (4.00)	0.04 (65535)	-0.009 (-0.34)	-0.026 (-2.65)	0.0009 (0.04)	0.054 (4.10)	-0.07 (65535)
		PC 4	0.066 (4.61)	0.012 (65535)	-0.03 (-0.97)	-0.008 (-0.66)	-0.016 (-0.74)	-0.007 (-0.35)	-0.029 (65535)
		PC 5	-0.04 (-2.69)	-0.006 (65535)	0.024 (0.02)	-0.03 (-2.11)	0.06 (2.02)	0.013 (0.62)	0.025 (65535)
		Intercept	0.711 (34.5)	0.465 (65535)	0.63 (13.34)	0.98 (58.72)	0.562 (16.22)	0.83 (31.23)	0.85 (65535)
	F	Sample Size	26	6	11	9	12	8	6
		R-Square	0.85	1.00	0.48	0.93	0.75	0.95	1.00
		F-test(Table)	24(3)	--	0.95(4.5)	8.26(6.4)	3.7(4.1)	8.6(6.4)	--

In the course of developing Motorized Trip Rate Models, PC1, PC3, PC4 are significant for combined cities data and for CP1. For city category of CP2, PC1, PC3, PC4 is negatively and PC2, PC5 is positively correlated with Motorized Trip Rate. For city category of CP3, PC2, PC3, PC4 and PC5 are negatively correlated with Motorized Trip Rate and positively with PC1.

PC1, PC2, PC4 are negatively and with PC3, PC5 positively correlated with Motorized Trip Rate for city category of CA1. For city category of CA2, PC1, PC3 are positively and significantly correlated. PC1, PC3, PC4 are observed to be negatively and PC2, PC5 positively correlated with Motorized Trip Rate for city category of CA3.

5.8. ANN Model-Selection of Training Function

ANN is a computing system made up of a number of simple, highly interconnected processing elements, which process information by their dynamic state response to external inputs. An Artificial Neural Network is a technique that simulates the operation of a human brain. It comprises of Input Layer, Hidden Layers and one Output layer each connected with connectors as shown in following Figure 5.4. The propagation of data from Input Layer via Hidden layers reaching the output layer is termed as one iteration. In Back propagation network the propagation of the data is both forward and backward. This network has a special feature which back propagates the error back from output to input layer. This process helps the network to learn the error percentage and gives the final value which is containing minimal error. So, in a back propagation network iteration is counted for one forward pass and one backward pass. The components of the Neural Network are described briefly below.

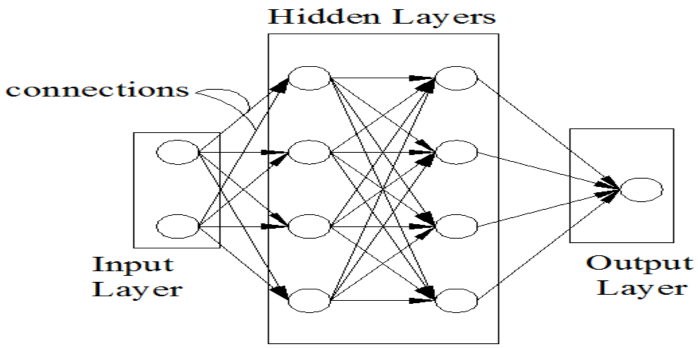


Figure 5.4: Components of Neural network

Neurons are the main components of a neural network. These are the functional units which perform mathematical computations and process the Output. It has Input and Output channels inside its cell body. The contact points between cell body and input or Outputs can be referred to as the Synapse of the human brain. These contact points have weights associated to them. The artificial neuron has two functions inside the cell body: one is an integrator that integrates the product of input and its corresponding weight; second one is a function that operates on the output of the integrator. Outcome of the second function is the Neuron Output. Figure 5.5 shows the schematic diagram of a neuron with both the functions.

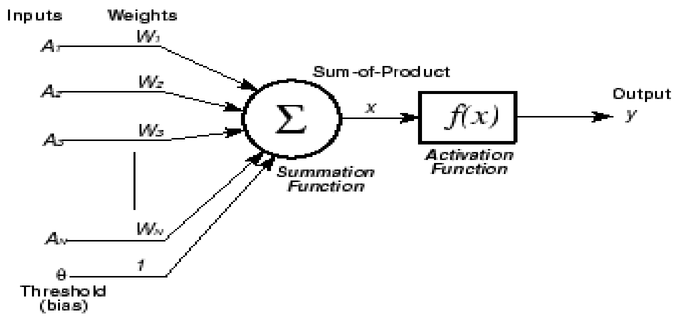


Figure 5.5: The Artificial Neuron

To calculate the neuron output value several mechanisms are available, some of them are: linear combination, mean-variance and min-max. The most basic way adopted for neuron output calculation is the linear combination. Firstly, the Inner product of inputs and corresponding weights are calculated. The resulting value is made to pass through an Activation function to introduce Non- Linearity.

Land use parameters have been taken as input and Trip rate has been considered as output data. Various hidden layer neurons have been considered for analysis. The performance of various training functions is given in Table 5.14.

Table 5.14: Performance of various training functions

Land-use Vs. Trip rate						
Network-Type	Training function	Hidden Neurons	Better MSE epoch	Epochs	Validation (R)/ Training (R)	Overall (R)
Feed-forward Back propagation	Trainscg	9	0.007 at 39	45	0.92/0.94	0.93
		10	0.022 at 15	21	0.87/0.94	0.92
		11	0.003 at 27	33	0.94/0.94	0.94
	Trainlm	9	0.013 at 20	26	**0.95/0.99**	**0.96**
		10	0.012 at 34	36	**0.97/0.99**	**0.97**
		11	0.014 at 17	23	**0.92/0.98**	**0.96**
	Traingd	9	0.004 at 1000	1000	0.96/0.90	0.88
		10	0.035 at 1000	1000	0.83/0.89	0.87
		11	0.050 at 1000	1000	0.96/0.91	0.86
	Traingdm	9	0.006 at 1000	1000	0.79/0.86	0.87
		10	0.025 at 1000	1000	0.83/0.88	0.87
		11	0.018 at 960	966	0.68/0.90	0.86
Feed-forward Back propagation	Trainrp	9	0.004 at 49	55	0.95/0.93	0.92
		10	0.020 at 13	19	0.86/0.91	0.86
		11	0.001 at 18	24	0.98/0.89	0.88
	Traincgp	9	0.010 at 40	46	0.94/0.94	0.95
		10	0.012 at 13	19	0.88//0.95	0.92
		11	0.002 at 38	44	0.93/0.94	0.94
	Traincgf	9	0.002 at 40	46	0.97/0.96	0.96
		10	0.021 at 14	20	0.88/0.95	0.93
		11	0.002 at 20	26	**0.99**/0.93	0.93
	Trainbfg	9	0.002 at 50	56	**0.98**/0.96	0.95
		10	0.007 at 36	42	0.98/**0.97**	0.94
		11	0.009 at 30	36	**0.88**/0.94	0.93

It is observed that Trainlm has better performance (R-Value) followed by Traincgf and Trainbfg. So, for further work, Trainlm training function was considered.

5.9. ANN Model for Trip Rate - All Cities Data

The trip rate of an area is directly or indirectly influenced by some variables. These may be socio-economic, and Land use variables. So it can be stated that the combined influence of such variables is useful in establishing a relation with trip rates of that area. So to establish this relation, ten variables from socio-economic data and ten variables from land use were selected for the study. The details of the data are given in Table 5.15. Trip rates of each of the city have also been taken from the secondary source. These variables are used to bring out an estimated trip rate based on the surveyed trip rate value of each city. This section mainly focuses on the relation with trip rates. Combined socio-economic and land use variables are considered as inputs for the artificial neural network model.

ANN working process is as indicated below

(1) ANN network architecture for the given data is selected.

(2) The input parameters selected are sent through the network then trained accordingly using the type of learning functions available.

(3) Weights and biases are automatically updated based on the network structure adopted.

(4) Weights and biases are saved which decides the outcome of the training process.

(5) This process is repeated for a required number of iterations until the results are good and the final network is saved.

Table 5.15: Input Parameters of the Network

S.No	Parameter	Units	Parameter Type
1	Population	Persons (In Lakhs)	Socio-economic
2	Area	sq.km	
3	Population Density	persons/sq.km	
4	Male	%	
5	Female	%	
6	Per Capita Income	Indian Rupees	
7	City Buses	Nos	
8	Road Safety Index	Value	
9	Road Density	km/sq.km	
10	Registered Vehicles	Nos (In thousands)	
11	Residential	%	Land use
12	Commercial	%	
13	Industrial	%	
14	Public Area	%	
15	Recreational	%	
16	Transport	%	

S.No	Parameter	Units	Parameter Type
17	Agricultural	%	
18	Water bodies	%	
19	Open Space	%	
20	Other land use	%	

Network Architecture

The selected network is a two layer feed forward network with 20 neurons in the Input layer. 20 neurons are selected in the hidden layer for further process. The Output layer is set for one neuron which is the trip rate of the selected city. The network architecture is as shown in Figure 5.6. Data used for development of ANN Model is given in Table 4.4.

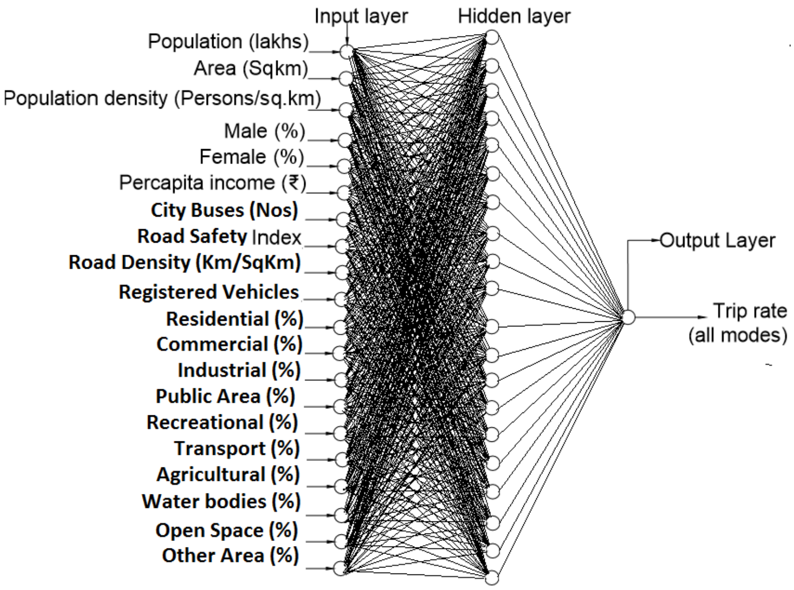


Figure 5.6: Network Architecture for Socio-economic and Land use Parameter vs. Trip Rate

Input neurons, each neuron corresponding to a Parameter are shown in Figure 5.6. Data is divided into the ratio of 70:15:15 for training, validation, and testing purposes in the ANN. Each neuron in the input layer is connected directly to every neuron of the Hidden layer. Trainlm is selected as Training function for neural network process. Output neuron (Target data) is trip rate for selected city. Division of data is given in Table 5.16.

Table 5.16: Division of Socio-economic and
Land use Data into Training, Validation and Testing Data sets

Input Data Size	Training set (70%)	Validation set (15%)	Testing set (15%)
26x20	18x20	4x20	4x20

Results and Interpretation

Performance of training, validation, and testing for the network with total inputs and trip rate as Output are presented in Figure 5.7. Training results like R-value and Mean Square Error (MSE) are given in Table 5.17.

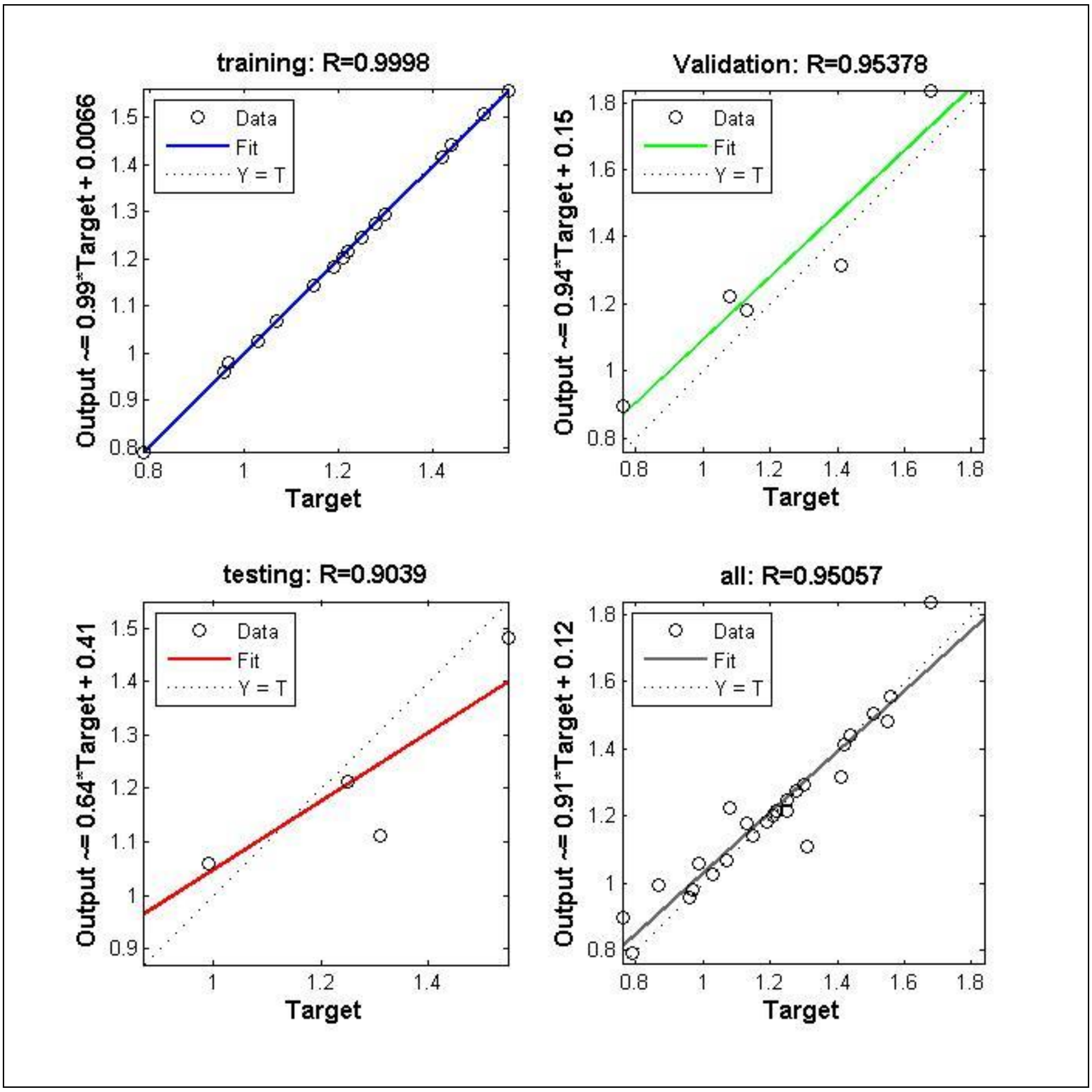


Figure 5.7: Performance of ANN with R-value (with Total Inputs)-Trip Rate

Table 5.17: Training Results of the ANN (with Total Inputs)-Trip Rate

Back Propagation with Trainlm (Total Input data)		
Overall (R)	MSE	Epoch
0.950	0.015	2

The above figure illustrates the graphical output of the neural network analysis. The ANN outputs are plotted versus the target as open circles. The finest linear fit is denoted by a discontinuous line. The actual fit (output {Trip rate from ANN} equal to targets {Trip rates fed to ANN process}) is showed by a solid line. If the fit is perfect (outputs exactly equals to targets), the slope of the solid line would be 1 and the y-intercept would be zero. Correlation coefficient (R-value) is also estimated for various data sets (training (70%), validation (15%), testing (15%) and total data (100%)). R-value is an indicator of how well the variation of output is explained by targets. If the R-value equals to 1, then there is a perfect correlation between outputs and targets. For this case, graph shows that values of slope, y-intercept and R-value of solid line are good as they are nearer to 1, 0, 1 respectively.

For every set of input applied to the network, the network output is matched with the target output. The difference of these two is considered as the error. The mean square error is calculated from following expression.

$$mse = \frac{1}{Q}\sum_{k=1}^{Q} e(k)^2 = \frac{1}{Q}\sum_{k=1}^{Q} (t(k) - a(k))^2 \tag{5.2}$$

Where, Q = Number of observations; t(k) = target output of k^{th} observation; a(k) = network output of k^{th} observation; e(k) = difference between target output and network output of k^{th} observation.

For the given data, the training has best fit with correlation coefficient and slope nearer to 1 and also y-intercept nearer to 0. Comparatively, validation and testing data set yields a little deviation from the threshold values. The overall correlation coefficient for the given data is 0.95 and mean square error is 0.015.

Motorized Trip Rate (Target) Model

Performance of training, validation, and testing for the network with total inputs and Motorized Trip Rate as output are presented in figure 5.8. Training results like R-value and Mean Square Error (MSE) are given in Table 5.18.

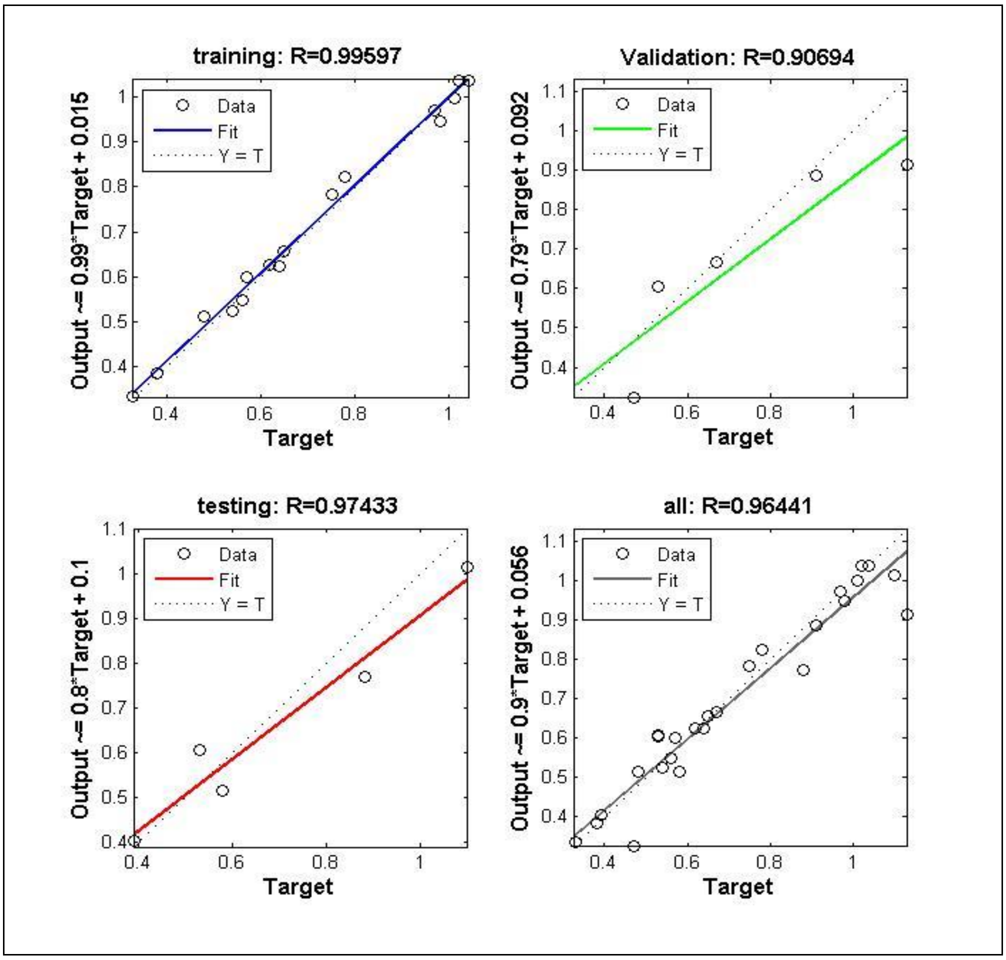


Figure 5.8: Performance of ANN (with Total Input) for Motorized Trip Rate

From the training data set of Figure 5.8, it is observed that solid line slope of 0.99 (1 is ideal) and y-intercept of 0.015 (zero is ideal). Validation data set has comparatively more deviation between target outputs and network outputs. The overall correlation coefficient is observed to be 0.96 and mean square error is 0.014, as shown in Table 5.18.

Table 5.18: Training Results of the ANN (with Total Inputs)-Motorized Trip Rate

Back Propagation with Trainlm (with Total Inputs)		
Overall (R)	MSE	Epoch
0.964	0.014	2

5.10. ANN Model for various categorised of cities based on population

5.10.1 ANN Model for CP1Category of Cities

Data of the cities with population less than 10 lakhs were taken for ANN process. Performance of training, validation, and testing for the network with total inputs and trip rate as output are presented in Figure 5.9. Training results like R-value and Mean Square Error (MSE) are given in Table 5.19.

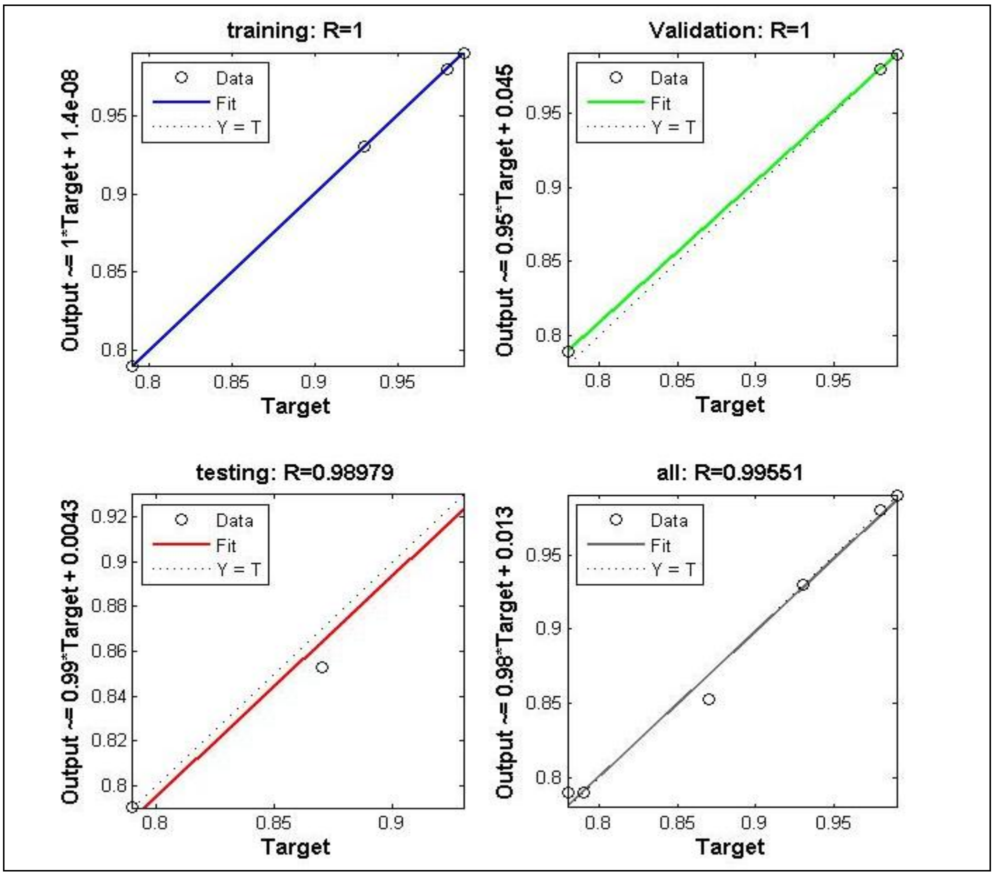


Figure 5.9: Performance of ANN for Trip Rate of CP1 Category of Cities

For the training, validation and testing data set, the slope of the solid line bordering on 1 and y-intercept is approaching zero. The overall correlation coefficient is 0.95 and mean square error at 3rd iteration is zero, as shown in Table 5.19.

Table 5.19: Training Results of the ANN (CP1 Category of Cities)-Trip Rate

Back Propagation with Trainlm (with Total Inputs)		
Overall (R)	MSE	Epoch
0.995	0.000	3

ANN Model for Motorized Trip Rate of CP1 Category of Cities:

Similar exercise was carried out for motorized trip rate. The results are presented in Figure 5.10 and Table 5.20.

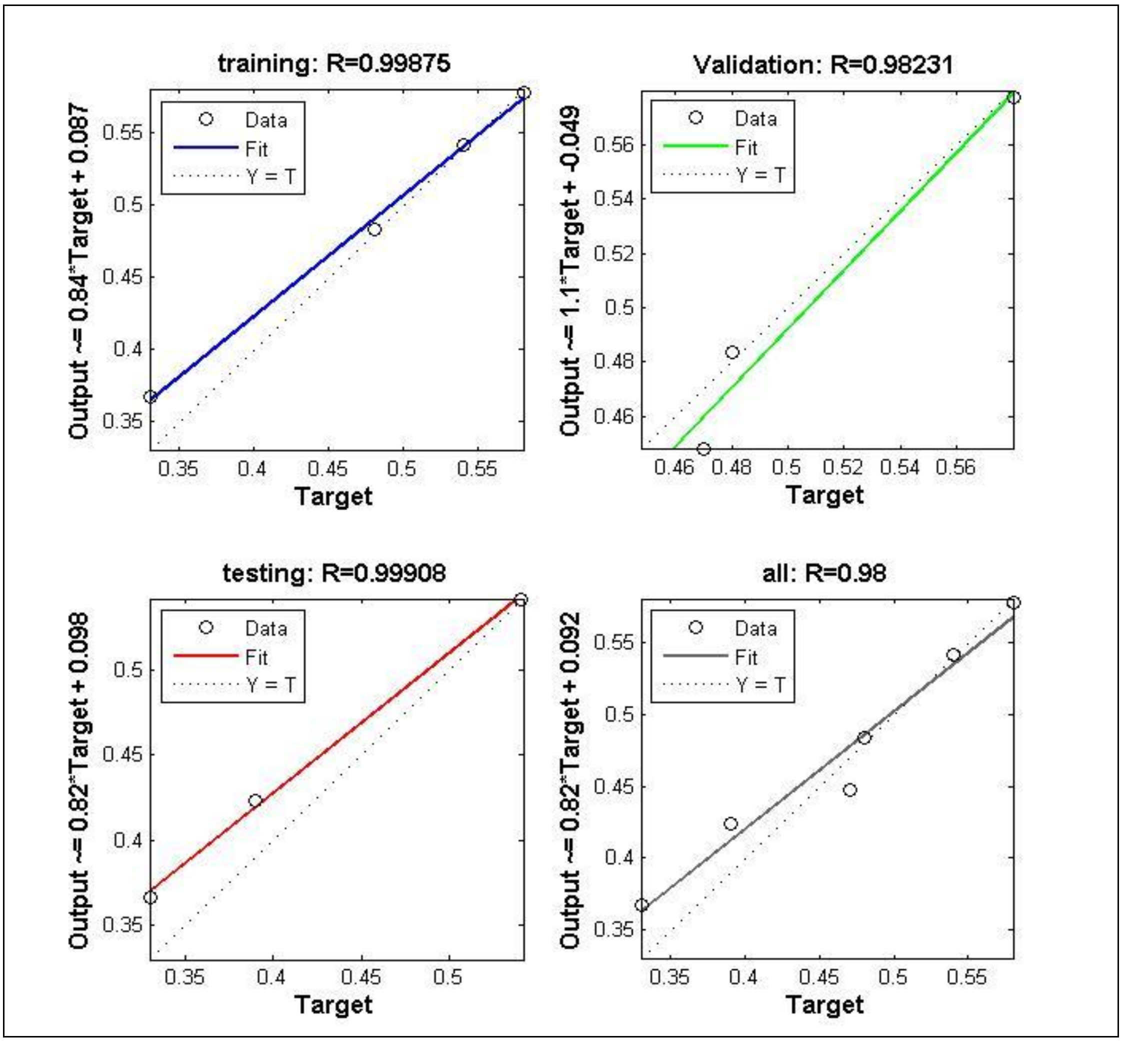


Figure 5.10: Performance of ANN for Motorized Trip Rate of CP1 Category of Cities

From the Figure 5.10, validation data set has a slope of solid line (between target output and network output) greater than 1. Y-intercept is approaching zero for all data sets. The overall correlation coefficient is 0.98 and mean square error is zero, as shown in Table 5.20.

Table 5.20: Training Results of the ANN ((CP1 Category of Cities))-Motorized Trip Rate

Back Propagation with Trainlm (with Total Inputs)		
Overall (R)	MSE	Epoch
0.98	0.000	1

5.10.2 ANN Model for CP2 Category of Cities

Data of the cities with population ranging between 10 to 40 lakhs were taken for ANN process. Performance of training, validation, and testing for the network with total inputs and Trip rate as output are presented in Figure 5.11. Training results like R-value and Mean Square Error (MSE) are given in Table 5.21.

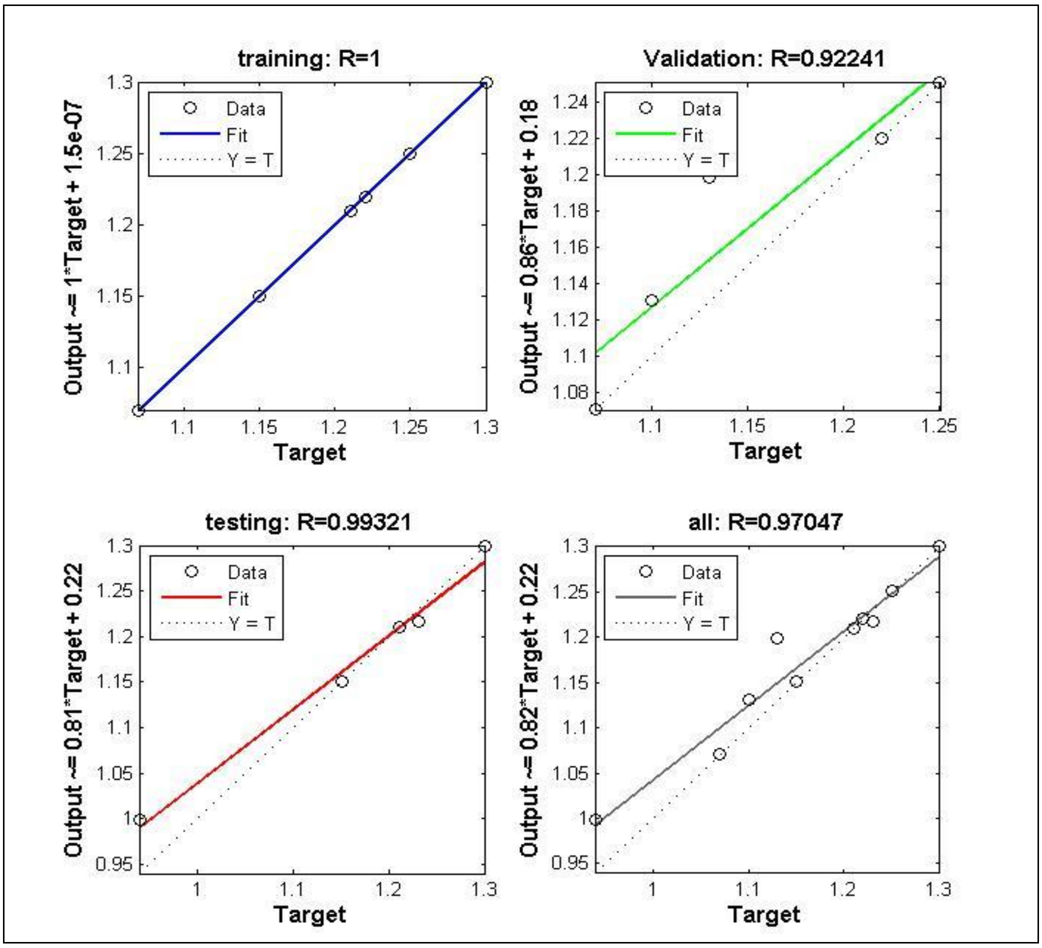


Figure 5.11: Performance of ANN for Trip Rate of CP2 Category of Cities

From the Figure 5.11, the slope of solid line for training data is 1. Whereas, the slope of solid line for validation and testing data is in the order of 0.8. The overall correlation coefficient for this case is 0.97 and mean square error at 3rd iteration is 0.001, as shown in Table 5.21.

Table 5.21: Training Results of the ANN (CP2 Category of Cities)-Trip Rate

Back Propagation with Trainlm (with Total Inputs)		
Overall (R)	MSE	Epoch
0.970	0.001	3

ANN Model for Motorized Trip Rate of CP2 Category of Cities:

Alike process was carried out for Motorized Trip Rate. Outcomes are presented in Figure 5.12 and Table 5.22.

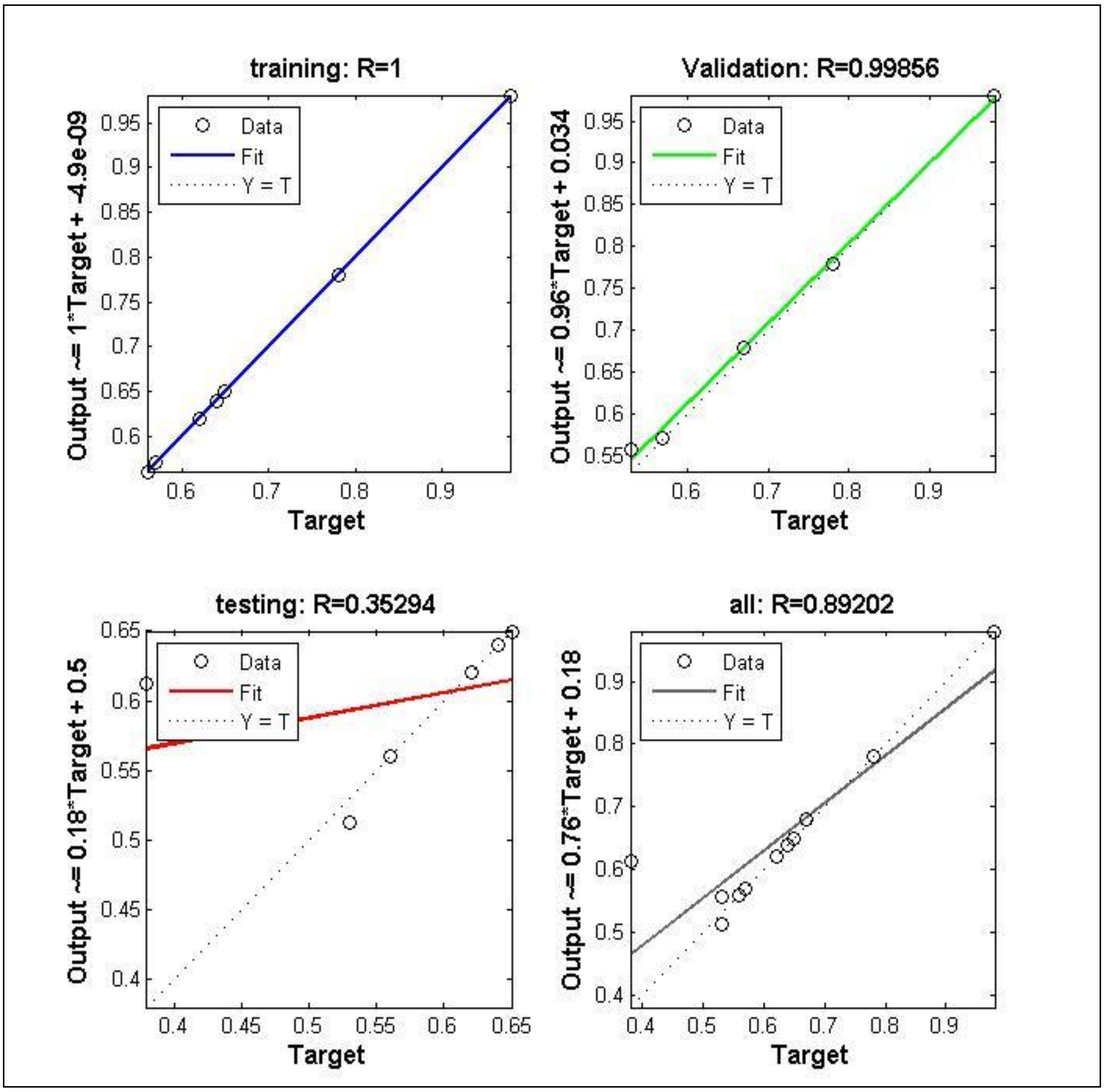


Figure 5.12: Performance of ANN for Motorized Trip Rate of CP2 Category of Cities

From the Figure 5.12, it is observed that training and validation data set fits better than the testing data. The overall correlation coefficient for this case is 0.89 and mean square error at 3rd iteration is zero, as given in Table 5.22.

Table 5.22: Training Results of the ANN (CP2 Category of Cities)-Motorized Trip Rate

Back Propagation with Trainlm (with Total Inputs)		
Overall (R)	MSE	Epoch
0.89	0.000	3

5.10.3 ANN Model for CP3 Category of Cities

Data of the cities with population more than 40 lakhs were taken for ANN process. Performance of training, validation, and testing for the network with total inputs and Trip rate as output are presented in Figure 5.13. Training results like R-value and Mean Square Error (MSE) are given in Table 5.23.

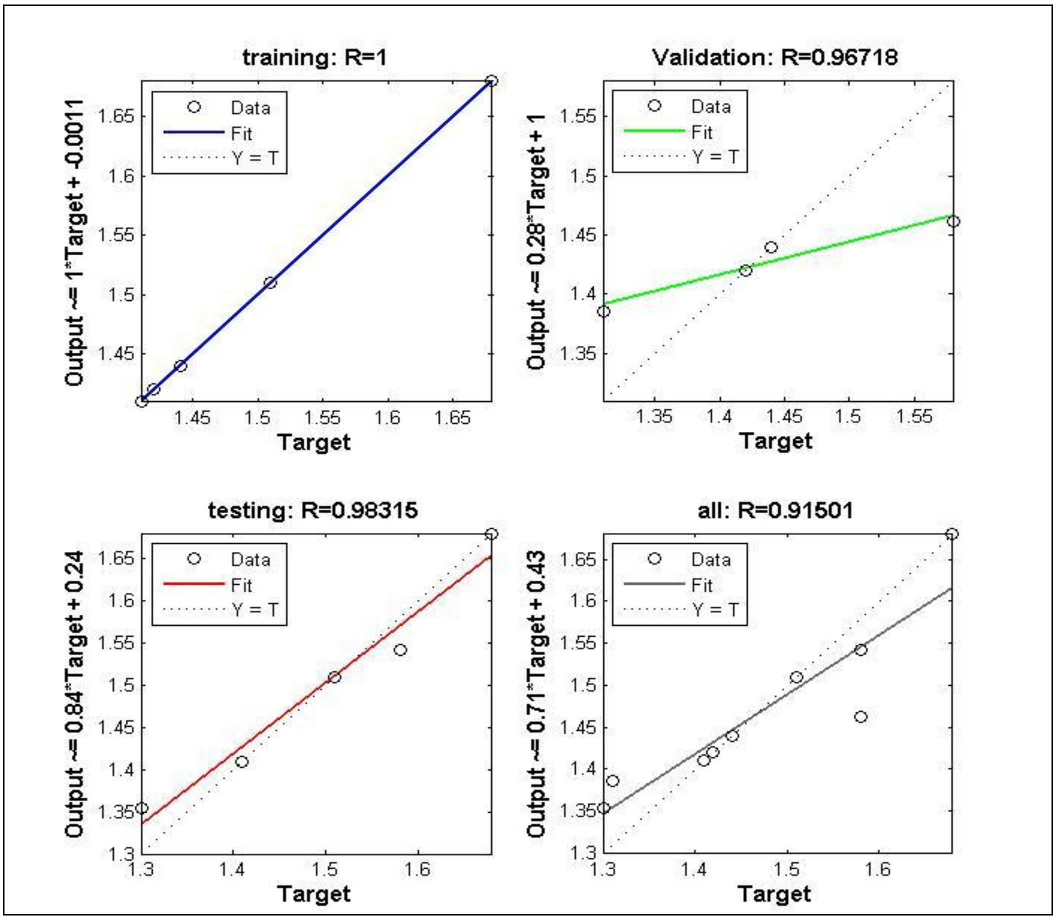


Figure 5.13: Performance of ANN for Trip Rate of CP3 Category of Cities

From the Figure 5.13 for training data set, the slope of solid line formed by target outputs and network outputs is 1(ideal case). The same is deviating excessively from 1 for validation data. The overall correlation coefficient is 0.91 and mean square error at 2nd iteration is 0.004, as shown in Table 5.23.

Table 5.23: Training Results of the ANN (CP3 Category of Cities)-Trip Rate

Back Propagation with Trainlm (with Total Inputs)		
Overall (R)	MSE	Epoch
0.915	0.004	2

ANN for Motorized Trip Rate of CP3 Category of Cities:

Parallel exercise was carried out for Motorized Trip Rate. The findings are presented in Figure 5.14 and Table 5.24.

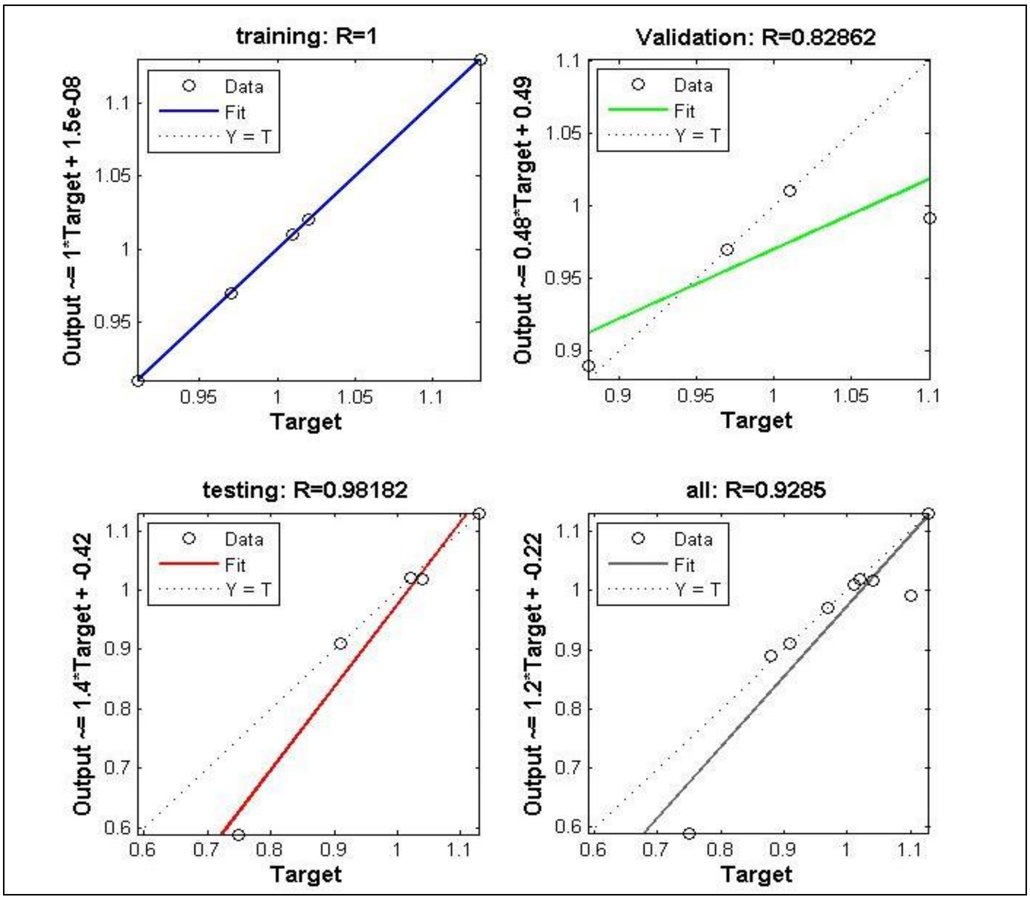


Figure 5.14: Performance of ANN for Motorized Trip Rate of CP3 Category of Cities

From the Figure 5.14 for training data, it is observed that desired and actual trend line are coinciding which indicates that the target and network outputs are best fitted. The slopes for validation and testing data are greater than one and lesser than one respectively. The overall correlation coefficient for given categories of cities is 0.92 and mean square error is 0.002, as shown in Table 5.24.

Table 5.24: Training Results of the ANN (CP3 Category of Cities)-Motorized Trip Rate

Back Propagation with Trainlm (with Total Inputs)		
Overall(R)	MSE	Epoch
0.928	0.002	3

Summary of ANN Model Results- Population Category:

Out of three categories of cities based on population, ANN model with CP1, raw data as input yield better results. For Trip Rate, Overall Correlation Coefficient for this category is 0.99 with mean square error (MSE) of zero. Motorized trip rate has Overall Correlation Coefficient of 0.96 and mean square error (MSE) of zero.

5.11. ANN Model for various categorised cities based on city area

5.11.1 ANN Model for CA1 Category of Cities

Data of the cities with the area less than 300 sq.km were taken for ANN process. Performance of training, validation, and testing for the network with total inputs and Trip rate as output are presented in Figure 5.15. Training results like R-value and Mean Square Error (MSE) are given in Table 5.25.

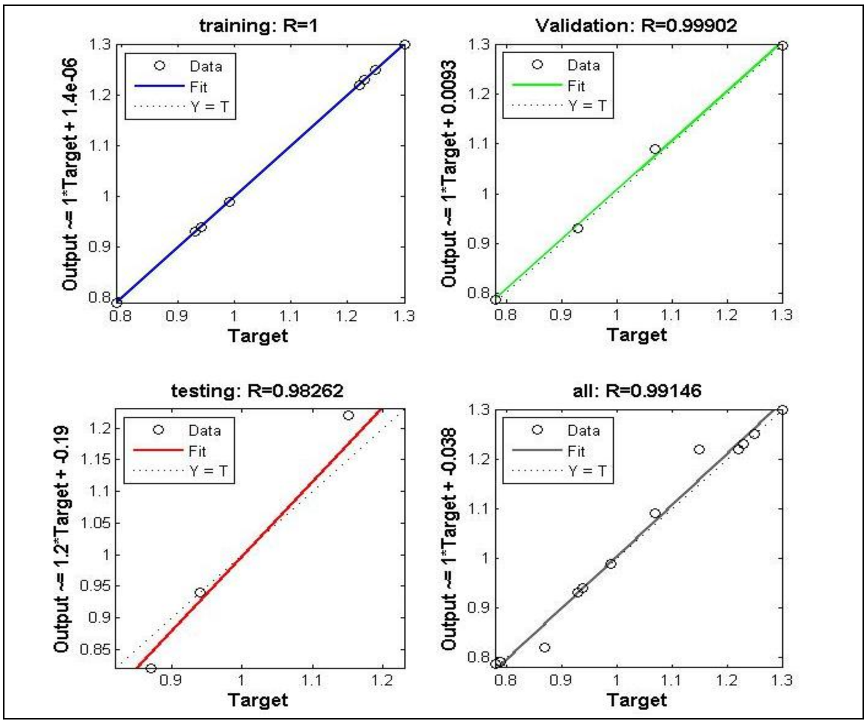


Figure 5.15: Performance of ANN for Trip Rate of CA1 Category of Cities

From the Figure 5.15 for training, validation and testing, network outputs are coinciding target outputs. The overall correlation coefficient is 0.99 and mean square error at 3rd iteration is zero, as given in Table 5.25.

Table 5.25: Training Results of the ANN (CA1 Category of Cities)-Trip Rate

Back Propagation with Trainlm (with Total Inputs)		
Overall (R)	MSE	Epoch
0.991	0.000	3

ANN Model for Motorized Trip Rate of CA1 Category of Cities:

Similar process is worked out for Motorized Trip Rate. Results are presented in Figure 5.16 and Table 5.26.

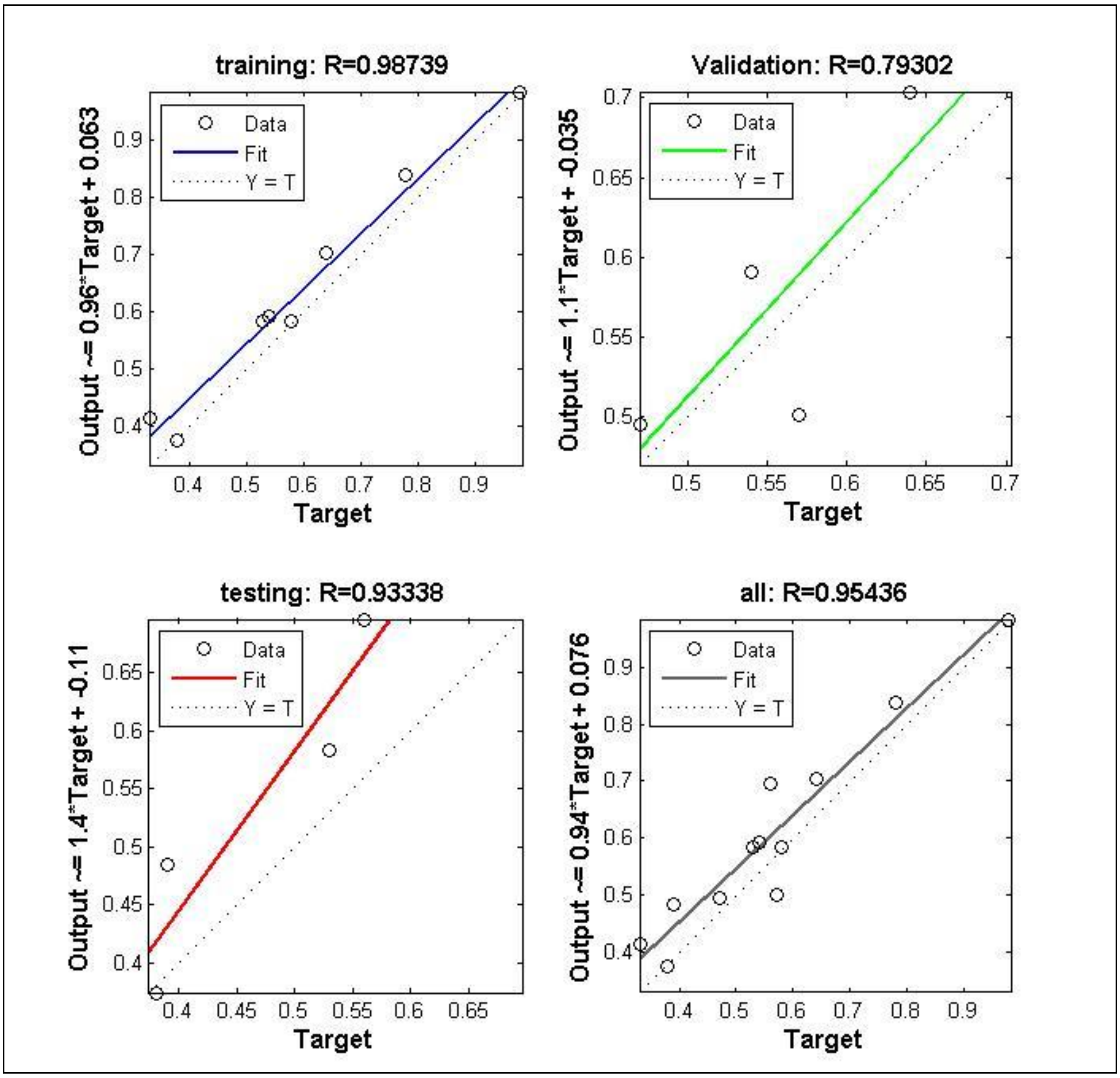


Figure 5.16: Performance of ANN for Motorized Trip Rate of CA1 Category of Cities

From the Figure 5.16 for validation and testing data, it is observed that network outputs are over estimated than the target outputs for most of the observations. The overall correlation coefficient is 0.95 and mean square error is 0.002, as shown in Table 5.26.

Table 5.26: Training Results of the ANN (CA1 Category of Cities)-Motorized Trip Rate

Back Propagation with Trainlm (with Total Inputs)		
Overall (R)	MSE	Epoch
0.954	0.002	1

5.11.2 ANN Model for CA2 Category of Cities

Data of the cities with area ranging between 300 to 1000 sq.km were taken for ANN process. Performance of training, validation, and testing for the network with total inputs and Trip rate as output are presented in Figure 5.17. Training results like R-value and Mean Square Error (MSE) are given in Table 5.27.

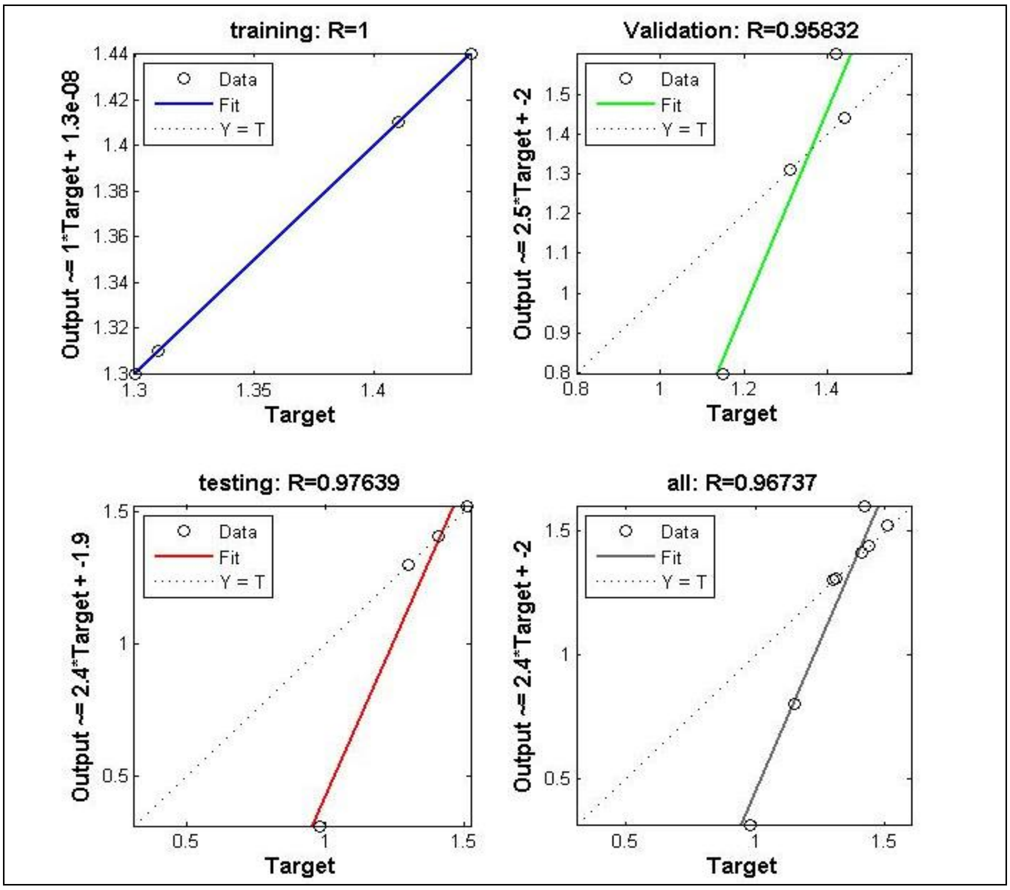


Figure 5.17: Performance of ANN for Trip Rate of CA2 Category of Cities

From the Figure 5.17, the network outputs are over estimated for all data sets except for training data. As a result, the mean square error is comparatively higher. The overall correlation coefficient is 0.96 and the mean square error at 3^{rd} iteration is 0.039, as presented in Table 5.27.

Table 5.27: Training Results of the ANN (CA2 Category of Cities)-Trip Rate

Back Propagation with Trainlm (with Total Inputs)		
Overall (R)	MSE	Epoch
0.967	0.039	3

ANN Model for Motorized Trip Rate of CA2 Category of Cities:

Parallel process was made for Motorized Trip Rate. The findings are presented in Figure 5.18 and Table 5.28.

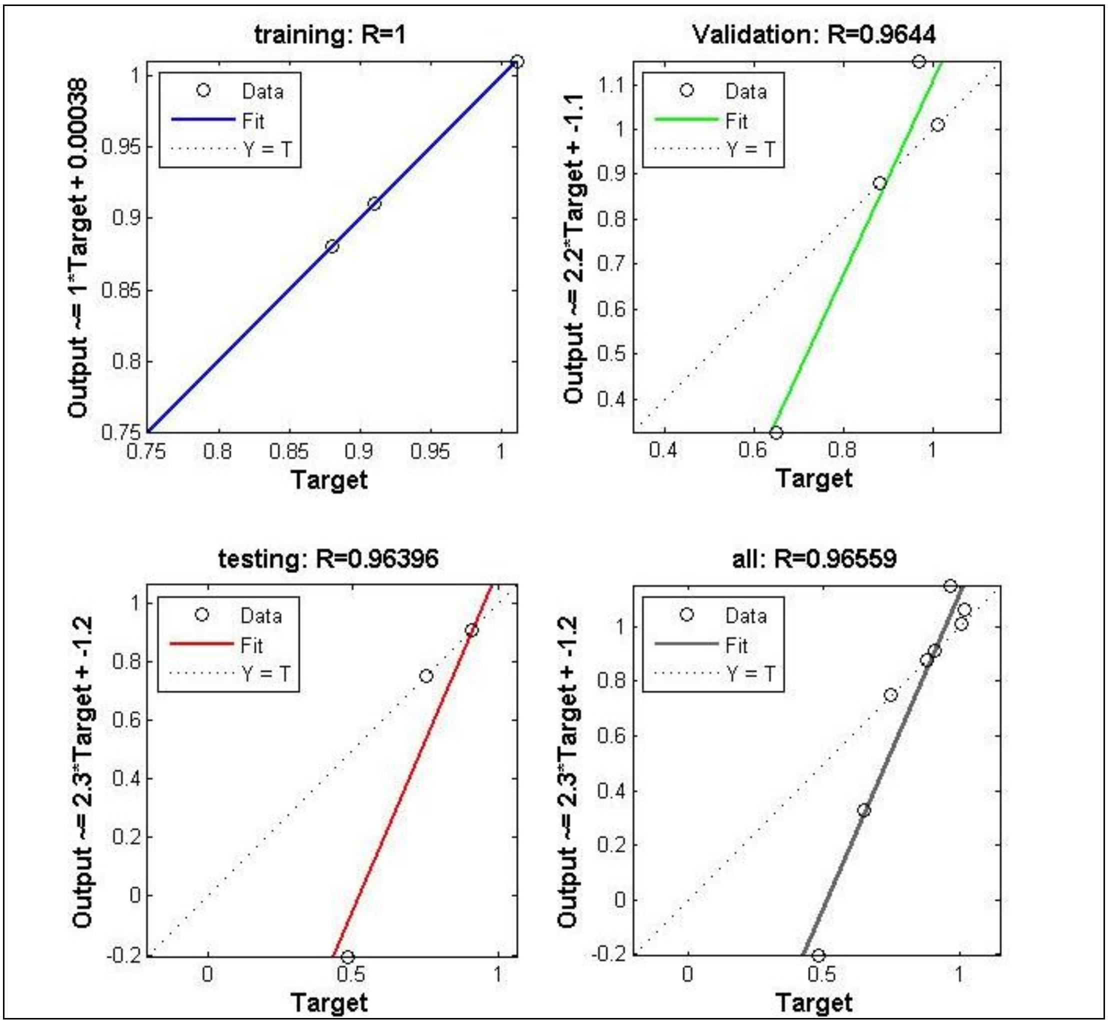


Figure 5.18: Performance of ANN for Motorized Trip Rate of CA2 Category of Cities

From Figure 5.18, the solid line (in the above graphs) is getting deviated from the dotted line for all data sets except for training data set. The deviation leads to higher value of mean square error. The overall correlation coefficient is 0.96 and mean square error at 2nd iteration is 0.034, as shown in Table 5.28.

Table 5.28: Training Results of the ANN (CA2 Category of Cities)-Motorized Trip Rate

Back Propagation with Trainlm (with Total Inputs)		
Overall (R)	MSE	Epoch
0.965	0.034	2

5.11.3 ANN Model for CA3 Category of Cities

Data of the cities with the area more than 1000 sq.km were taken for ANN process. Performance of training, validation, and testing for the network with total inputs and Trip rate as output are presented in Figure 5.19. Training results like R-value and Mean Square Error (MSE) are given in Table 5.29.

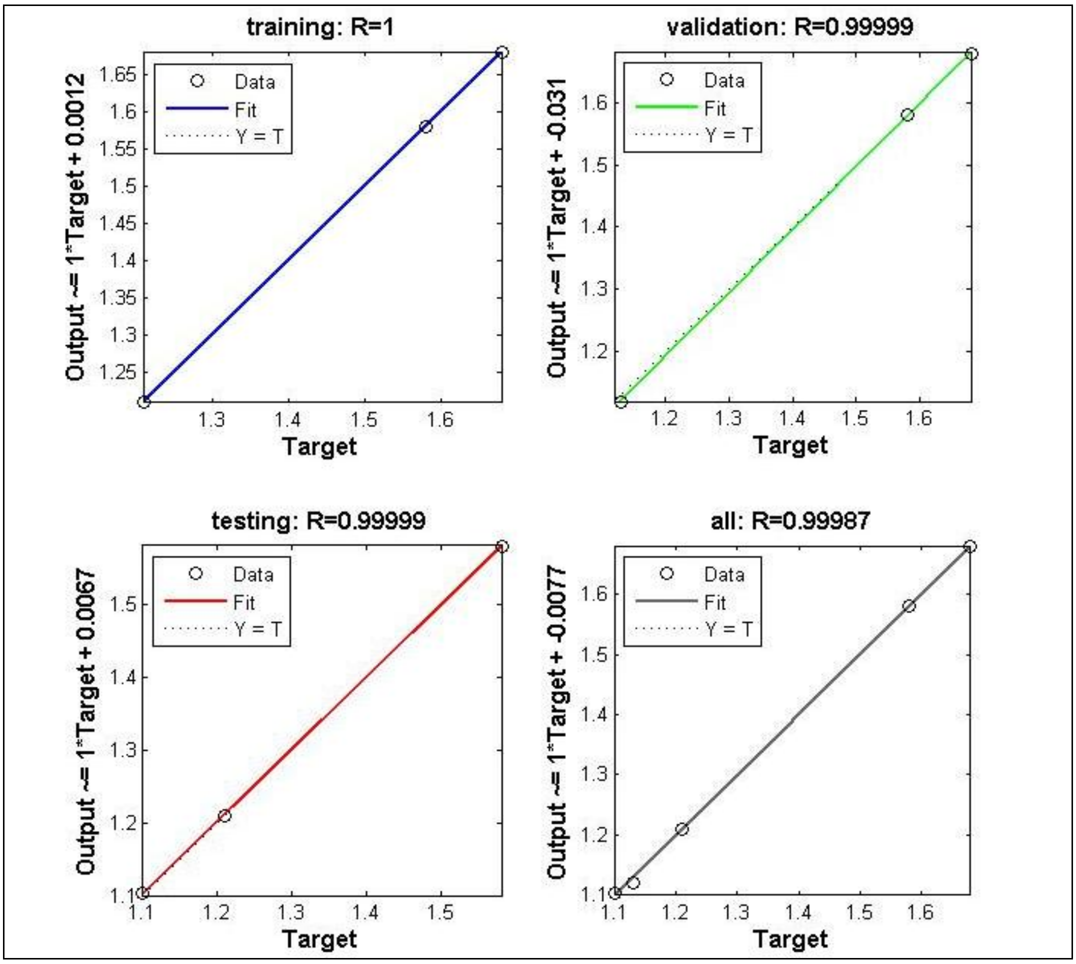


Figure 5.19: Performance of ANN for Trip Rate of CA3 Category of Cities

From Figure 5.19, it is observed that slope of the solid line for all data sets is 1 and y-intercept is almost zero. The overall correlation coefficient for this case is 0.99 and mean square error at 2nd iteration is zero, as presented in Table 5.29.

Table 5.29: Training Results of the ANN (CA3 Category of Cities)-Trip Rate

Back Propagation with Trainlm (with Total Inputs)		
Overall (R)	MSE	Epoch
0.999	0.000	2

ANN Model for Motorized Trip Rate of CA3 Category of Cities:

Alike exercise was carried out for Motorized Trip Rate. The outcome is given in Figure 5.20 and Table 5.30.

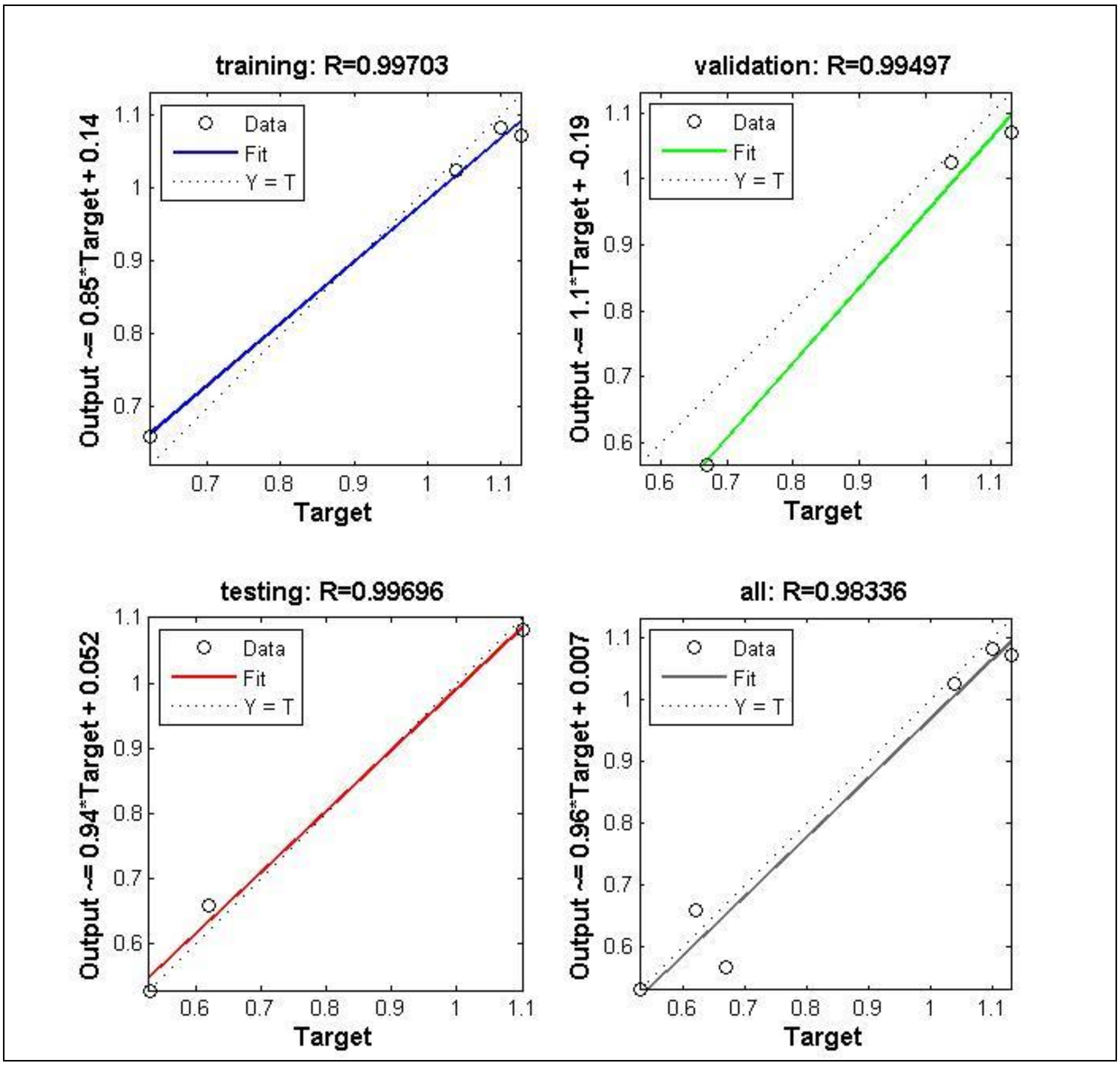


Figure 5.20: Performance of ANN for Motorized Trip Rate of CA3 Category of Cities

From the Figure 5.20, the slope of the solid line less than 1 for all data sets except for validation data sets. The overall correlation coefficient is 0.98 and mean square error for the given city category is 0.004, as shown in Table 5.30.

Table 5.30: Training Results of the ANN (CA3 Category of Cities)-Motorized Trip Rate

Back Propagation with Trainlm (with Total Inputs)		
Overall (R)	MSE	Epoch
0.983	0.004	1

Summary of ANN Model Results- City Area Category:

Out of three categories of cities based on city area, ANN model with CA3, raw data as input yield better results. For Trip Rate, Overall Correlation Coefficient for this category is 0.99 with mean square error (MSE) of zero. Motorized trip rate has Overall Correlation Coefficient of 0.98 and mean square error (MSE) of zero.

5.12. ANN Model with Principal Components

The network architecture using principal components is given in Figure 5.21. The selected network is a two layer feed forward network with back propagation algorithm. The input layer has five neurons which takes the data of the Principal components obtained by carrying out a Principal Component Analysis on the entire data. The first five principal components are considered as they describe 70 percent of the original data.

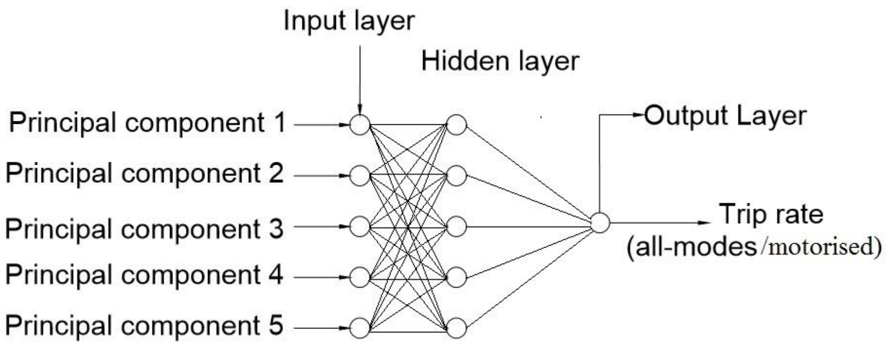


Figure 5.21: Network Architecture selected using Principal Components as Inputs

Hidden layer has been provided with five neurons. Activation function used for the work is Pure linear. This network is a fully connected network with all the neurons processing the data forward.

Output layer contains one neuron which carries the target data. The target data is surveyed trip rate values of all modes of transport collected for cities. A feed-forward back propagation network means the simulated values are back propagated to input layer and propagated forward again, till the minimal error value is achieved.

Five Principal Components Data of all cities were taken for ANN process. Performance of training, validation, and testing for the network with total inputs and Trip rate as output are presented in Figure 5.22. Training results like R-value and Mean Square Error (MSE) are given in Table 5.31.

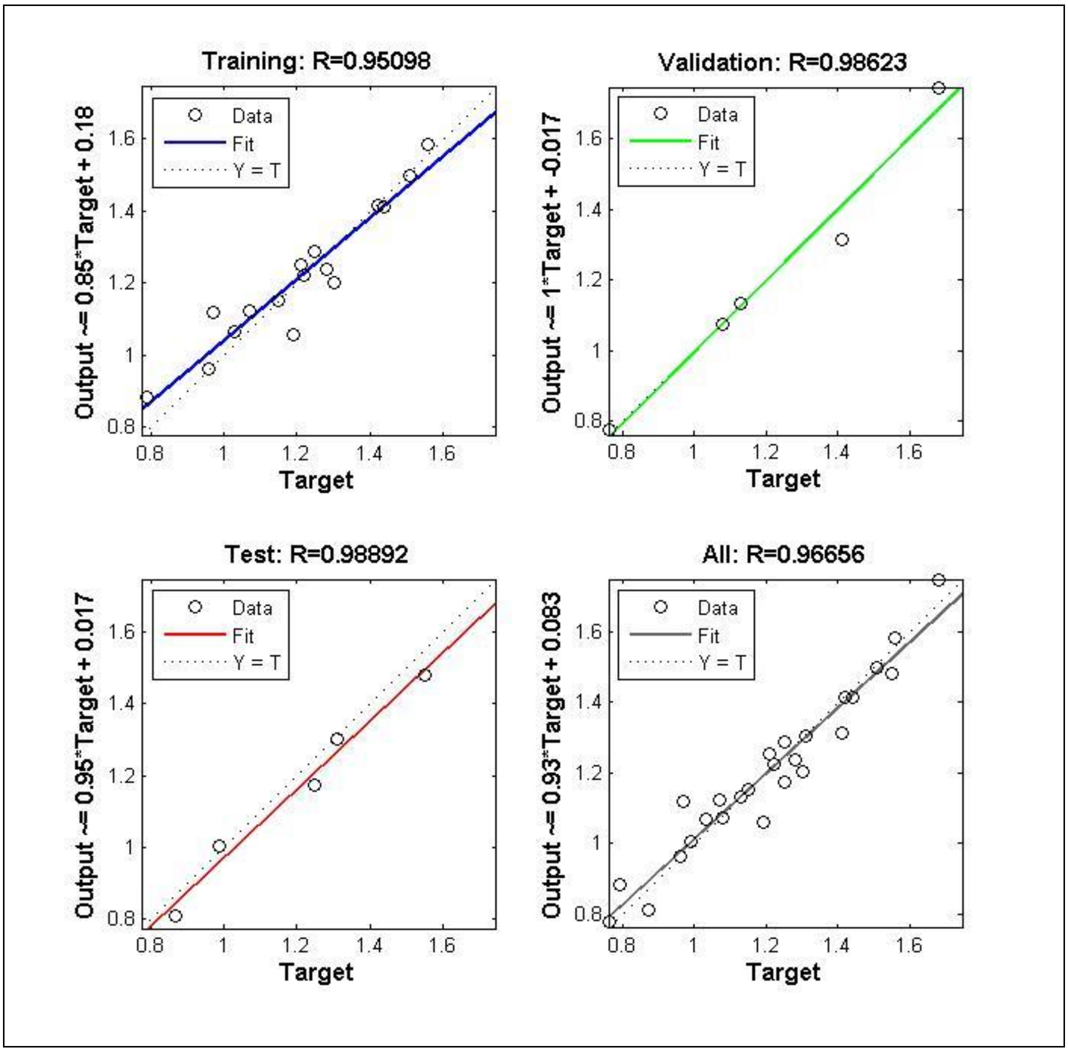


Figure 5.22: Performance of ANN (PCs) for Trip Rate

From the Figure 5.22, the slopes of the solid line between target and network outputs are 0.85,1, 0.95 for training, validation and testing data sets respectively. The overall correlation coefficient is 0.96 and mean square error at 3rd iteration is 0.002, as presented in Table 5.31.

Table 5.31: Training Results of the ANN (5 PCs) -Trip Rate

Back Propagation with Trainlm (5 PCs)		
Overall (R)	MSE	Epochs
0.966	0.002	3

PCA and ANN for Motorized Trip Rate :

Similar process was worked out with five principal components for Motorized Trip Rate. Results are presented in Figure 5.23 and Table 5.32.

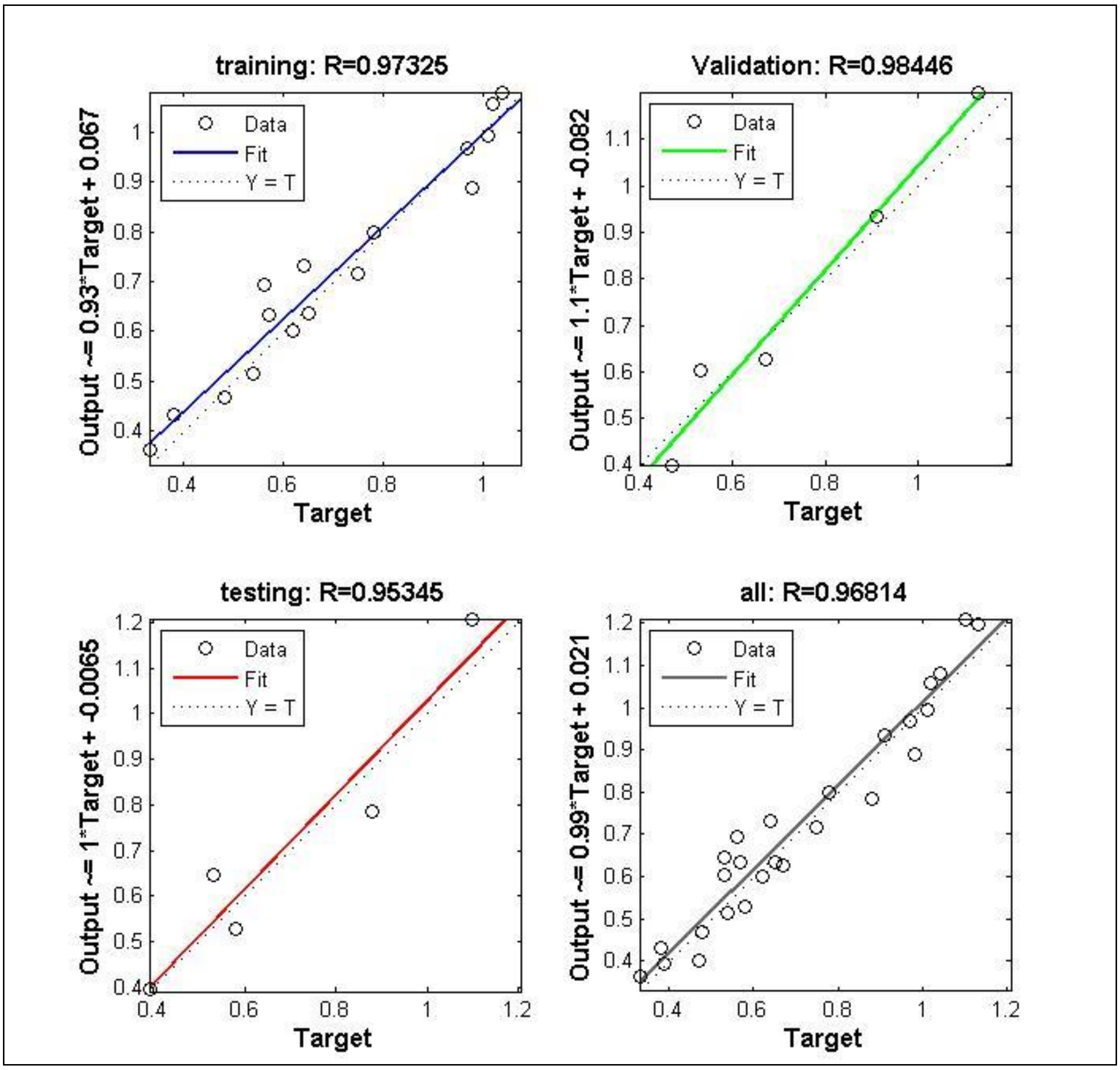


Figure 5.23: Performance of ANN (PCs) for Motorized Trip Rate

From the Figure 5.23, network outputs are well estimated by ANN process for given target outputs. However, a middling deviation exists in training data sets. The overall correlation coefficient is 0.96 and mean square error at 6^{th} iteration is 0.003, as presented in Table 5.32.

Table 5.32: Training Results of the ANN (PCs)-Motorized Trip Rate

Back Propagation with Trainlm (PCs)		
Overall (R)	MSE	Epochs
0.968	0.003	6

5.13. ANN Models with Principal Components for Various Categories of Cities based on Population

5.13.1 ANN Model with PCs for CP1 Category of Cities

Five Principal Components Data of cities with population less than 10 lakhs were taken for ANN process. Performance of training, validation, and testing for the network with total inputs and Trip rate as output are presented in Figure 5.24. Training results like R-value and Mean Square Error (MSE) are given in Table 5.33.

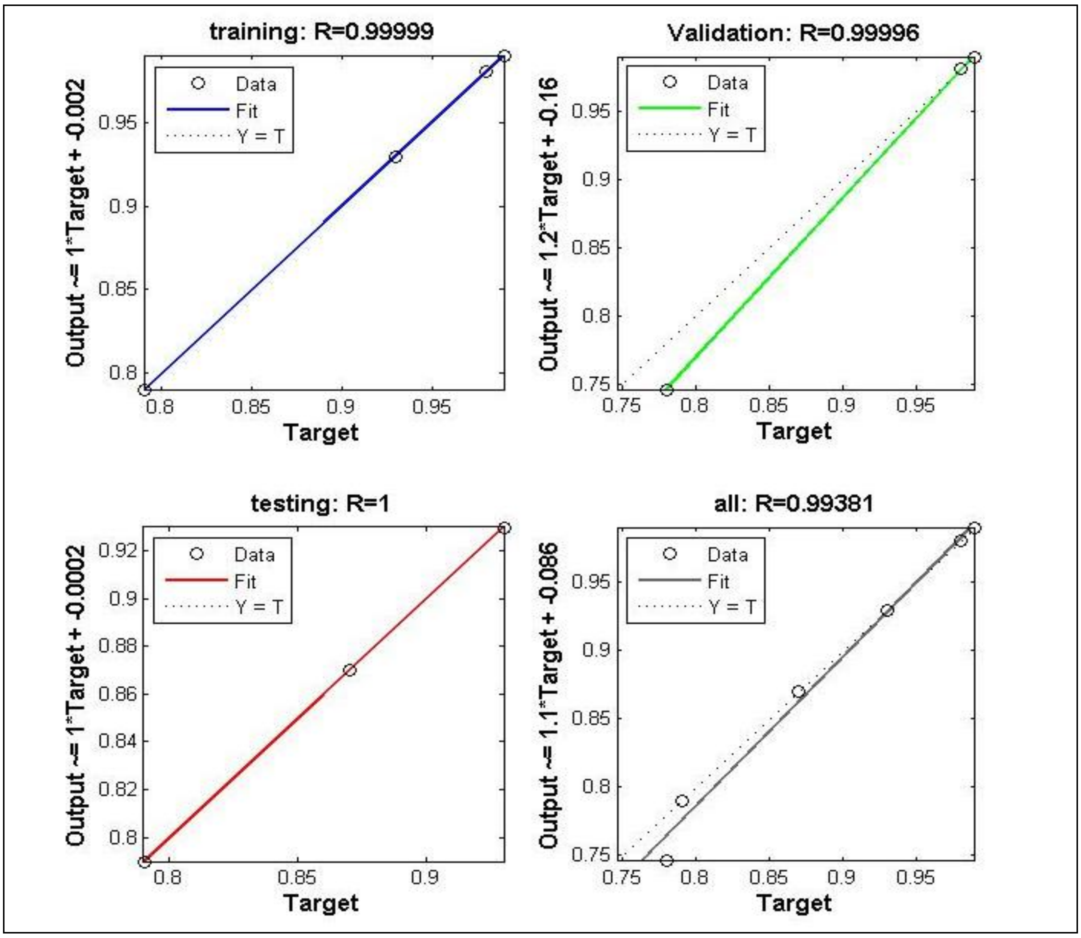


Figure 5.24: Performance of ANN (PCs) for Trip Rate-CP1

From the Figure 5.24, the solid and dotted line coincides for training and testing data sets. However, there is an over estimation of network outputs in the validation data set. The overall correlation coefficient is 0.99 and mean square error is zero, as given in Table 5.33.

Table 5.33: Training Results of the ANN (PCs)-Trip Rate-CP1

Back Propagation with Trainlm (PCs)		
Overall (R)	MSE	Epochs
0.993	0.000	3

PCA and ANN for Motorized Trip Rate of CP1 Category of Cities:

Parallel process was carried out with principal components of less than 10 lakhs population data for Motorized Trip Rate. The findings are presented in Figure 5.25 and Table 5.34.

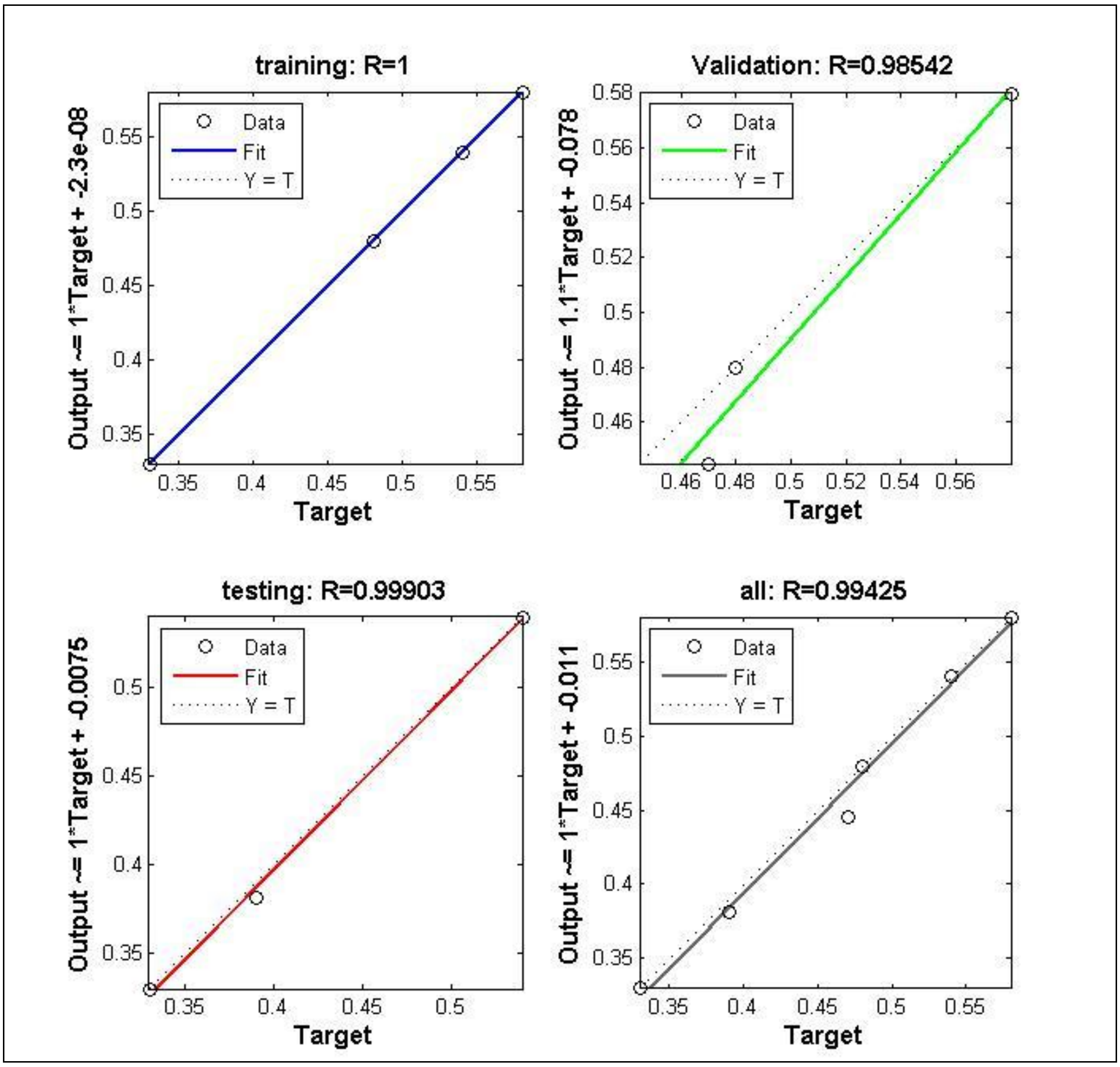


Figure 5.25: Performance of ANN (PCs) for Motorized Trip Rate-CP1

From the Figure 5.25, it is slopes of the solid line is 1 for all data sets except for validation data set. The overall correlation coefficient is 0.99 and mean square error at 4^{th} iteration is zero, as shown in Table 5.34.

Table 5.34: Training Results of the ANN (PCs)-Motorized Trip Rate-CP1

Back Propagation with Trainlm (PCs)		
Overall (R)	MSE	Epochs
0.994	0.000	4

5.13.2 ANN Model with PCs of CP2 Category of Cities

Five Principal Components Data of cities with population ranging from 10 to 40 lakhs were taken for ANN process. Performance of training, validation, and testing for the network with total inputs and Trip rate as output are presented in Figure 5.26. Training results like R-value and Mean Square Error (MSE) are given in Table 5.35.

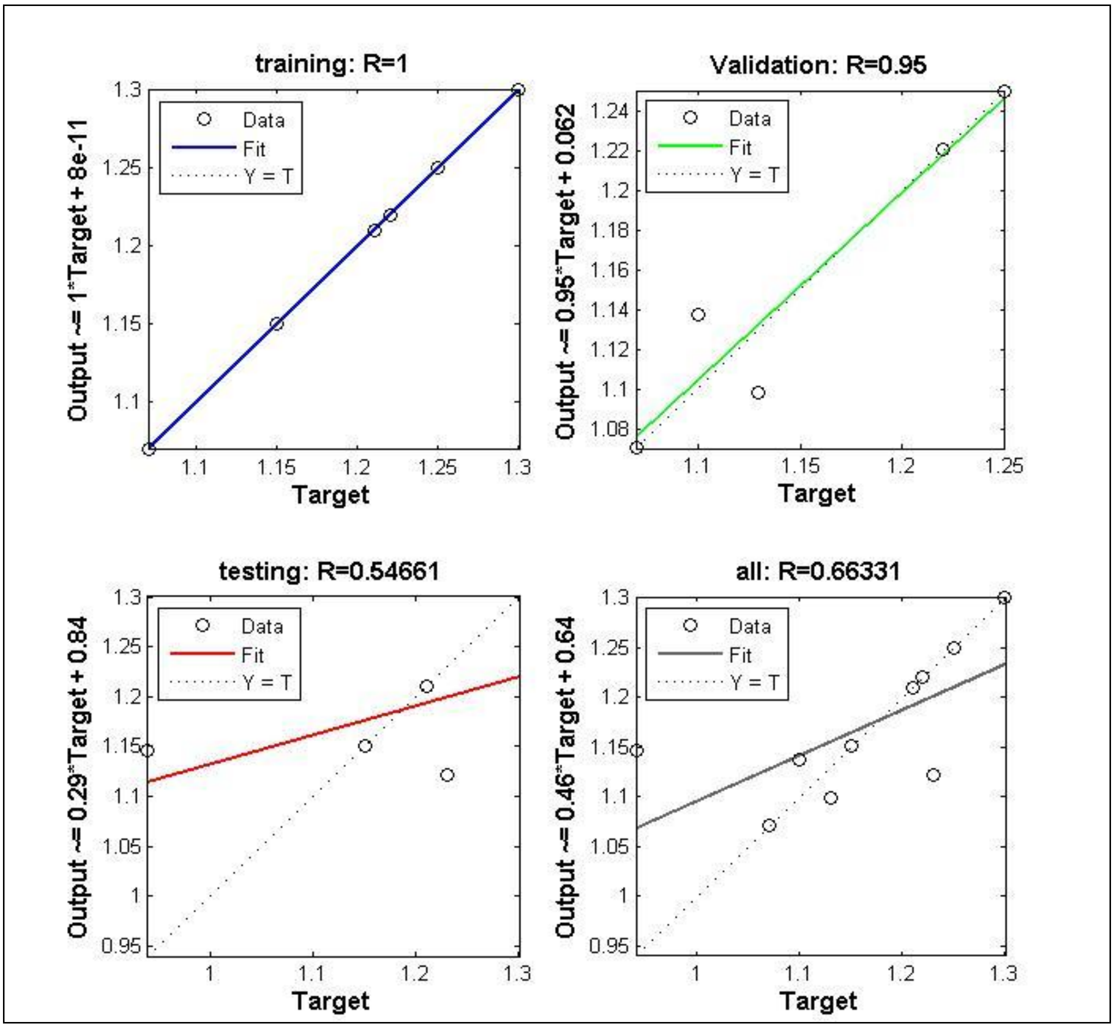


Figure 5.26: Performance of ANN (PCs) for Trip Rate-CP2

From the Figure 5.26, it is observed a significant deviation in the solid line from the dotted line in the testing and overall data set. The overall correlation coefficient is 0.66 and mean square error at 6th iteration is zero, as presented in Table 5.35.

Table 5.35: Training Results of the ANN (PCs)-Trip Rate-CP2

Back Propagation with Trainlm (PCs)		
Overall (R)	MSE	Epochs
0.663	0.000	6

PCA and ANN for Motorized Trip Rate of CP2 Category of Cities:

Similar exercise was carried out with five principal components of 10-40 lakhs population cities for Motorized Trip Rate. The outcomes are given in Figure 5.27 and Table 5.36.

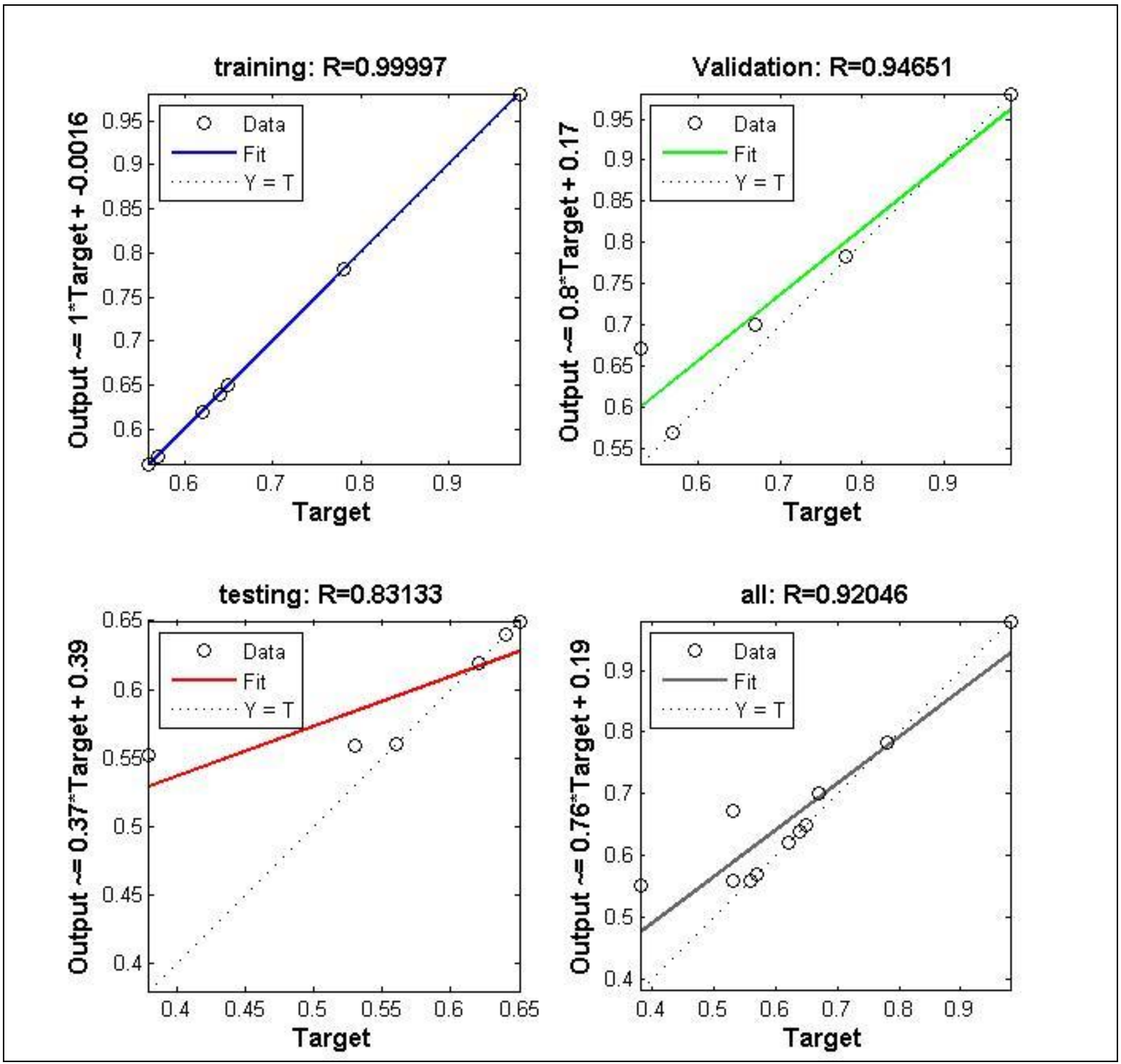


Figure 5.27: Performance of ANN (PCs) for Motorized Trip Rate-CP2

From the Figure 5.27, the slopes of solid lines are 1, 0.8, 0.37 for training, validation and testing data sets respectively. The overall correlation coefficient is 0.92 and mean square error at 2nd iteration is 0.004, as shown in Table 5.36.

Table 5.36: Training Results of the ANN (PCs)-Motorized Trip Rate-CP2

Back Propagation with Trainlm (PCs)		
Overall (R)	MSE	Epochs
0.920	0.004	2

5.13.3 ANN Model with PCs of CP3 Category of Cities

Five Principal Components Data of cities with population more than 40 lakhs were taken for ANN process. Performance of training, validation, and testing for the network with total inputs and Trip rate as output are presented in Figure 5.28. Training results like R-value and Mean Square Error (MSE) are given in Table 5.37.

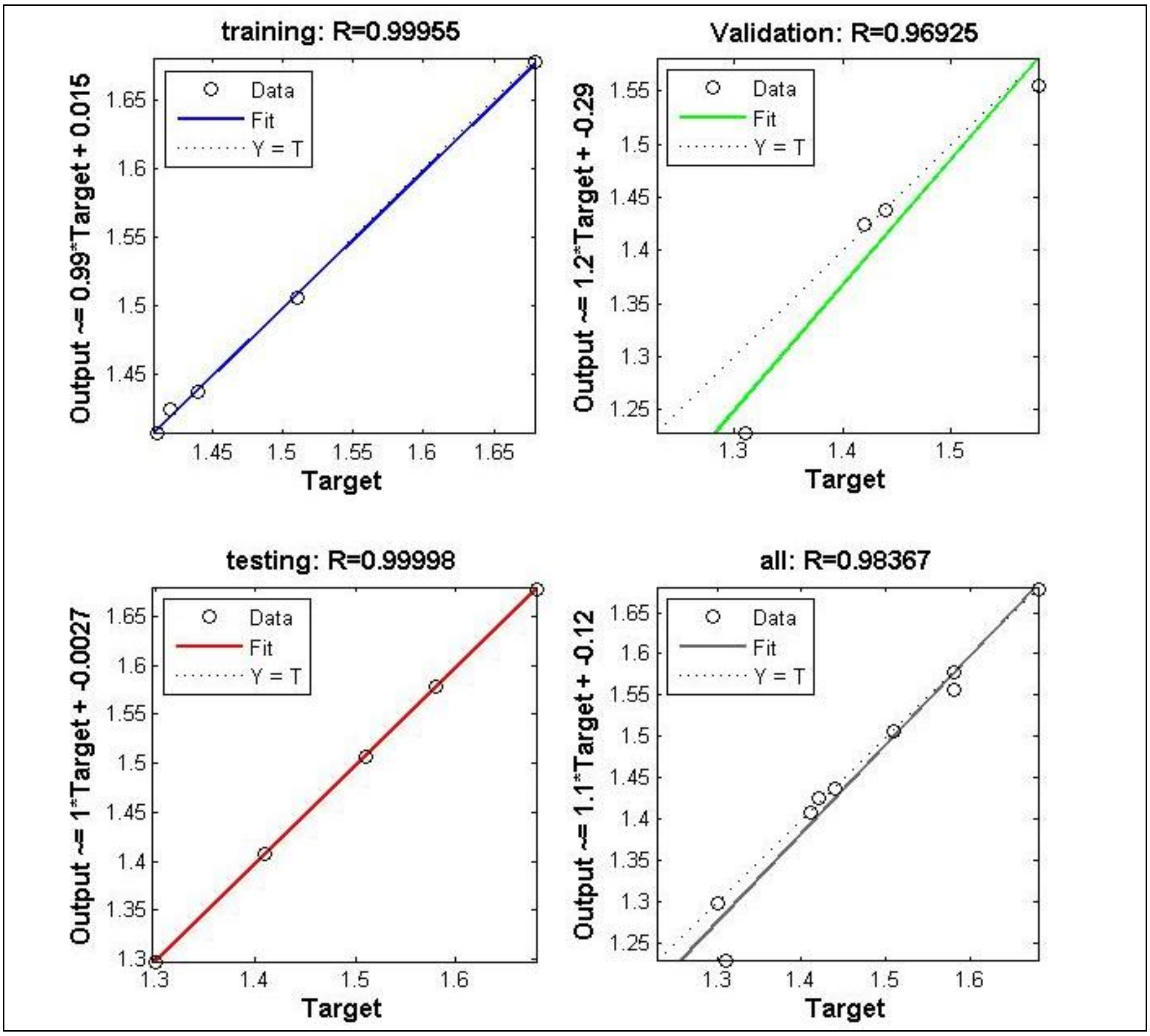


Figure 5.28: Performance of ANN (PCs) for Trip Rate-CP3

From the Figure 5.28, the network outputs estimated well by ANN process for training and testing data set. The overall correlation coefficient is 0.98 and mean square error at 2nd iteration is 0.001, as given in Table 5.37.

Table 5.37: Training Results of the ANN (PCs)-Trip Rate-CP3

Back Propagation with Trainlm (PCs)		
Overall (R)	MSE	Epochs
0.983	0.001	2

PCA and ANN for Motorized Trip Rate of CP3 Category of Cities:

Parallel exercise was carried out principal components of more than 40 lakhs population cities for Motorized Trip Rate. The results are shown in Figure 5.29 and Table 5.38.

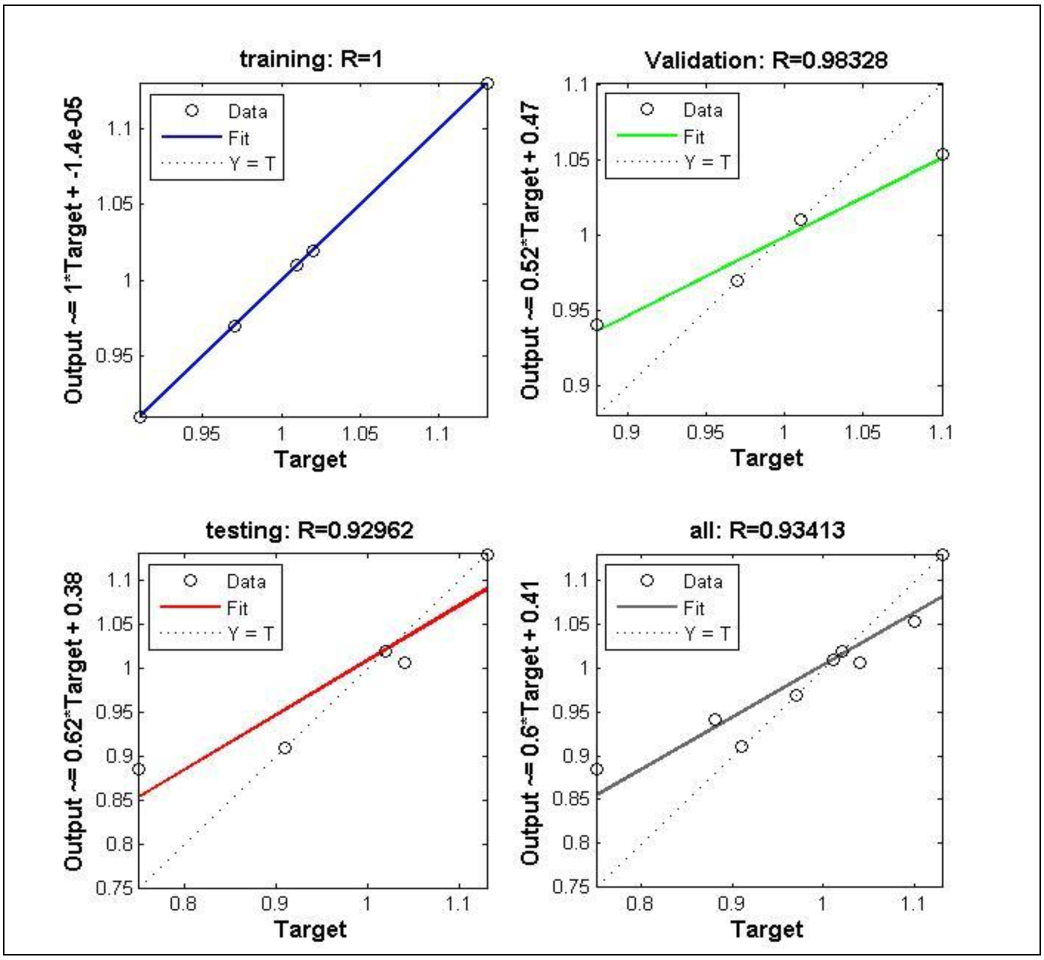


Figure 5.29: Performance of ANN (PCs) for Motorized Trip Rate-CP3

From the Figure 5.29, it is observed that a great deviation in the slopes from 1 for validation and testing data set. However, this is 1 for training data set. The overall correlation coefficient is 0.93 and mean square error at 3rd iteration is 0.001, as presented in Table 5.38.

Table 5.38: Training Results of the ANN (PCs)- Motorized Trip Rate-CP3

Back Propagation with Trainlm (PCs)		
Overall (R)	MSE	Epochs
0.934	0.001	3

Summary of ANN Model Results- Population Category & PC as Input:

Out of three categories of cities based on population, ANN model with CP1, Principal Components as input yield better results. For Trip Rate, Overall Correlation Coefficient for this category is 0.99 with mean square error (MSE) of zero. Motorized trip rate has Overall Correlation Coefficient of 0.99 and mean square error (MSE) of zero.

5.14. ANN Models with Principal Components for Various Categories of Cities based on City Area

5.14.1 ANN Model with PCs for CA1 Category of Cities

Five Principal Components Data of cities with city area less than 300 sq.km were taken for ANN process. Performance of training, validation, and testing for the network with total inputs and Trip rate as output are presented in Figure 5.30. Training results like R-value and Mean Square Error (MSE) are given in Table 5.39.

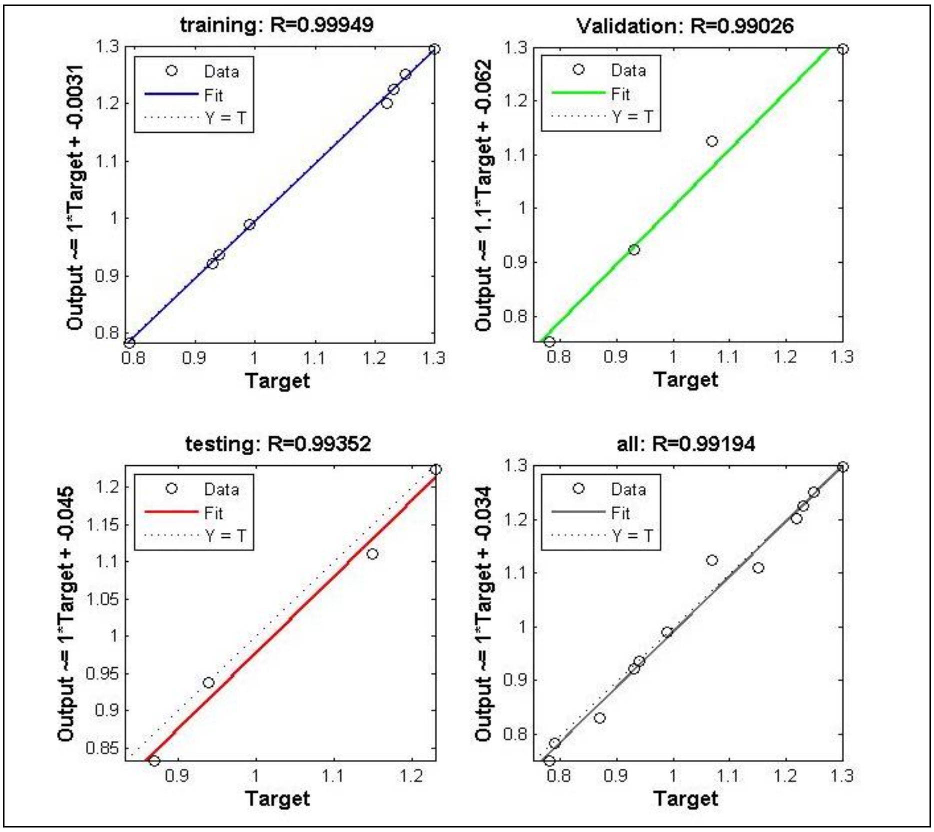


Figure 5.30: Performance of ANN (PCs) for Trip Rate-CA1

From the Figure 5.30, the network outputs are best estimated for training and testing data set. However, there is an over estimation of the same for validation data set. The overall correlation coefficient is 0.99 and mean square error is zero, as shown in Table 5.39.

Table 5.39: Training Results of the ANN (PCs)-Trip Rate -CA1

Back Propagation with Trainlm (PCs)		
Overall (R)	MSE	Epochs
0.991	0.000	2

PCA and ANN for Motorized Trip Rate of CA1 Category of Cities:

Similar exercise was performed for five principal components of less than 300 sqkm City Area for Motorized Trip Rate. The findings are given in Figure 5.31 and Table 5.40.

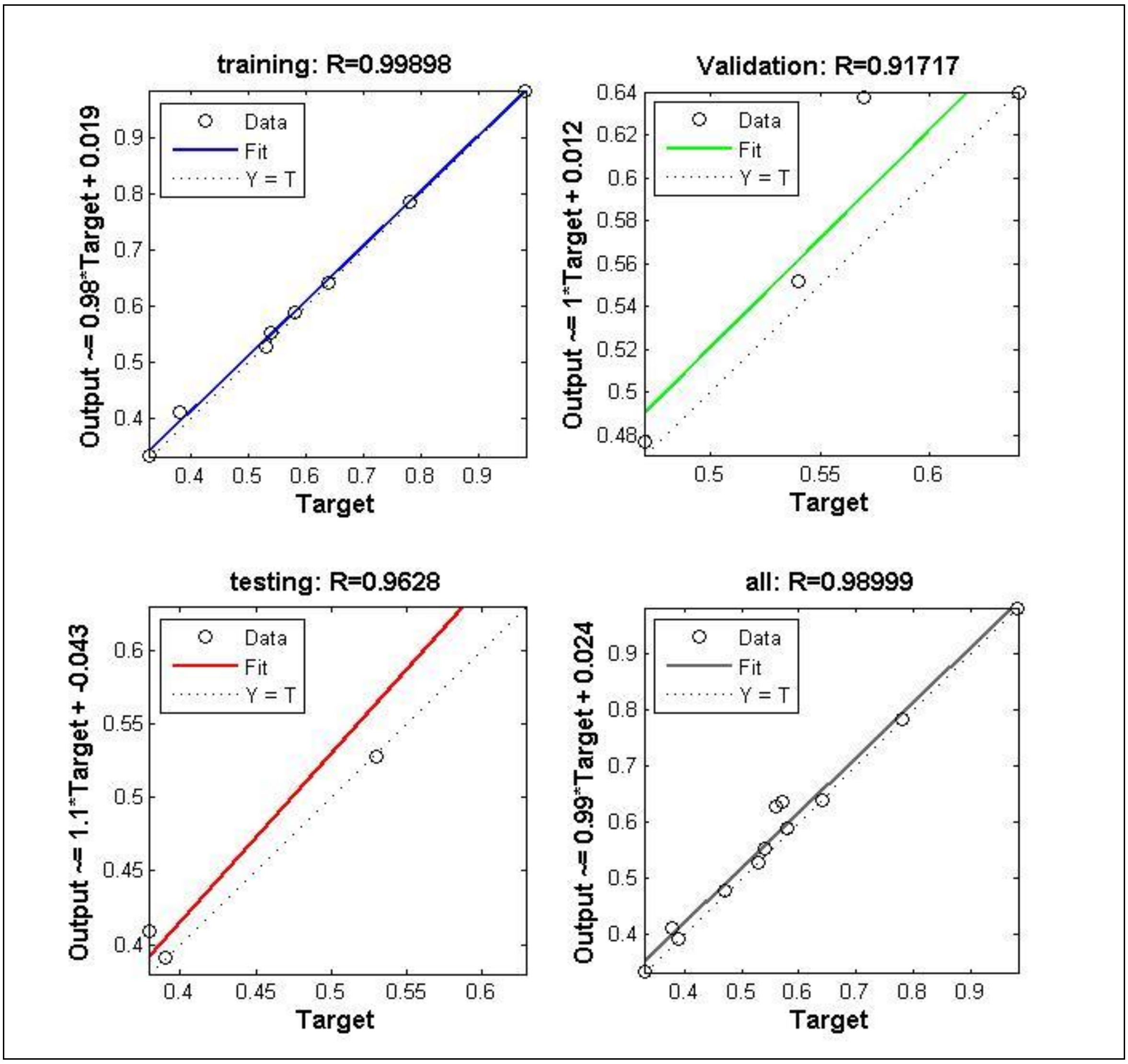


Figure 5.31: Performance of ANN (PCs) for Motorized Trip Rate-CA1

From the Figure 5.31, it is observed that the slopes of solid lines are 0.98, 1, 1.1 for training, validation and testing data set respectively. The overall correlation coefficient is 0.98 and mean square error at 2nd iteration is 0.001, as presented in Table 5.40.

Table 5.40: Training Results of the ANN (PCs)-Motorized Trip Rate-CA1

Back Propagation with Trainlm (PCs)		
Overall (R)	MSE	Epochs
0.989	0.001	2

5.14.2 ANN Model with PCs of CA2 Category of Cities

Five Principal Components Data of cities with city area ranging from 300 to 1000 sq.km were taken for ANN process. Performance of training, validation, and testing for the network with total inputs and Trip rate as Output are presented in Figure 5.32. Training results like R-value and Mean Square Error (MSE) are given in Table 5.41.

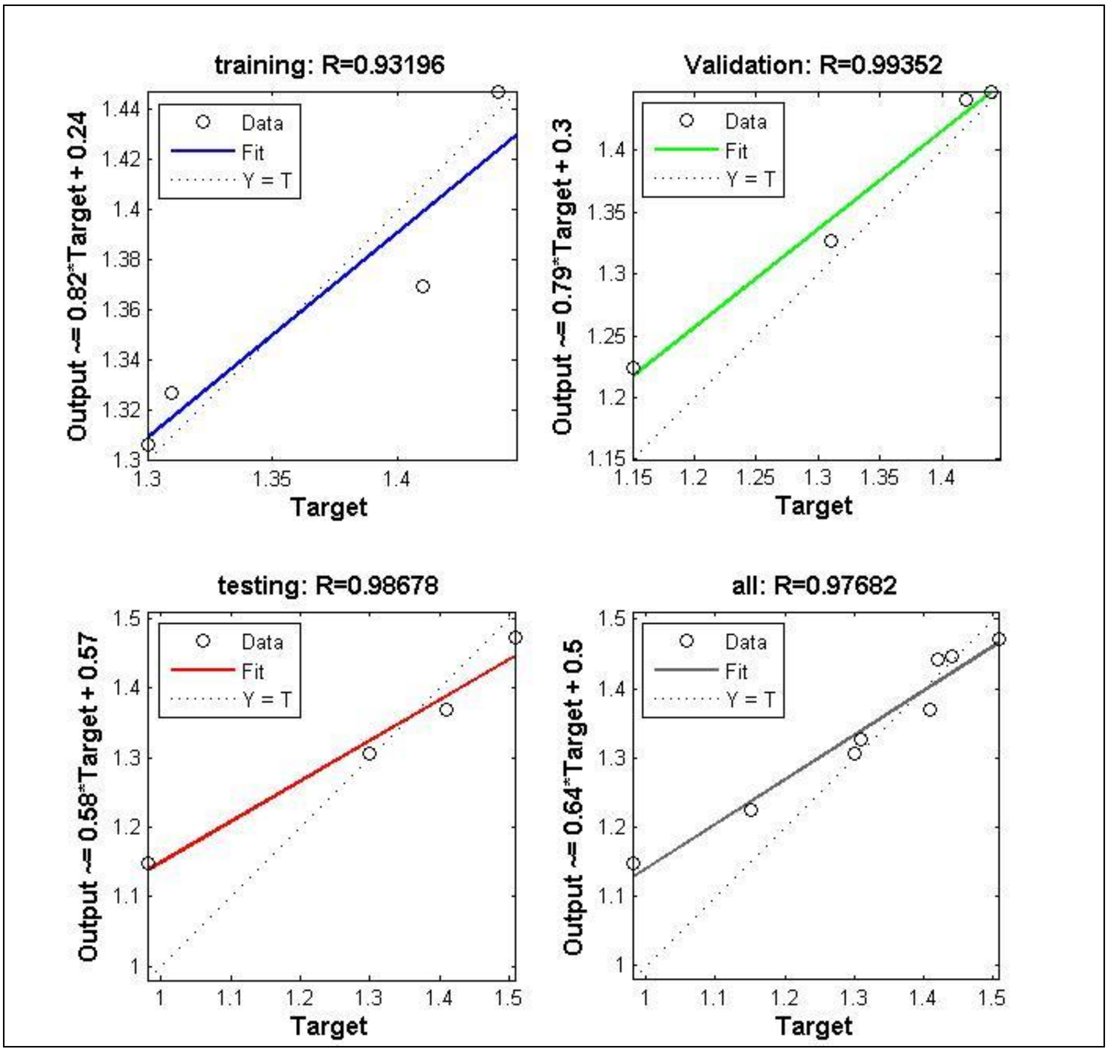


Figure 5.32: Performance of ANN (PCs) for Trip Rate-CA2

From the Figure 5.32, the slopes of solid line deviates from dotted line for all data sets. This deviation is high for testing data. The values of y-intercept is also high which is undesirable. The overall correlation coefficient is 0.97 and mean square error is 0.001, as shown in Table 5.41.

Table 5.41: Training Results of the ANN (PCs)-Trip Rate-CA2

Back Propagation with Trainlm (PCs)		
Overall (R)	MSE	Epochs
0.976	0.001	1

PCA and ANN for Motorized Trip Rate of CA2 Categories of Cities:

Similar exercise was carried out for Motorized Trip Rate. The results are presented in Figure 5.33 and Table 5.42.

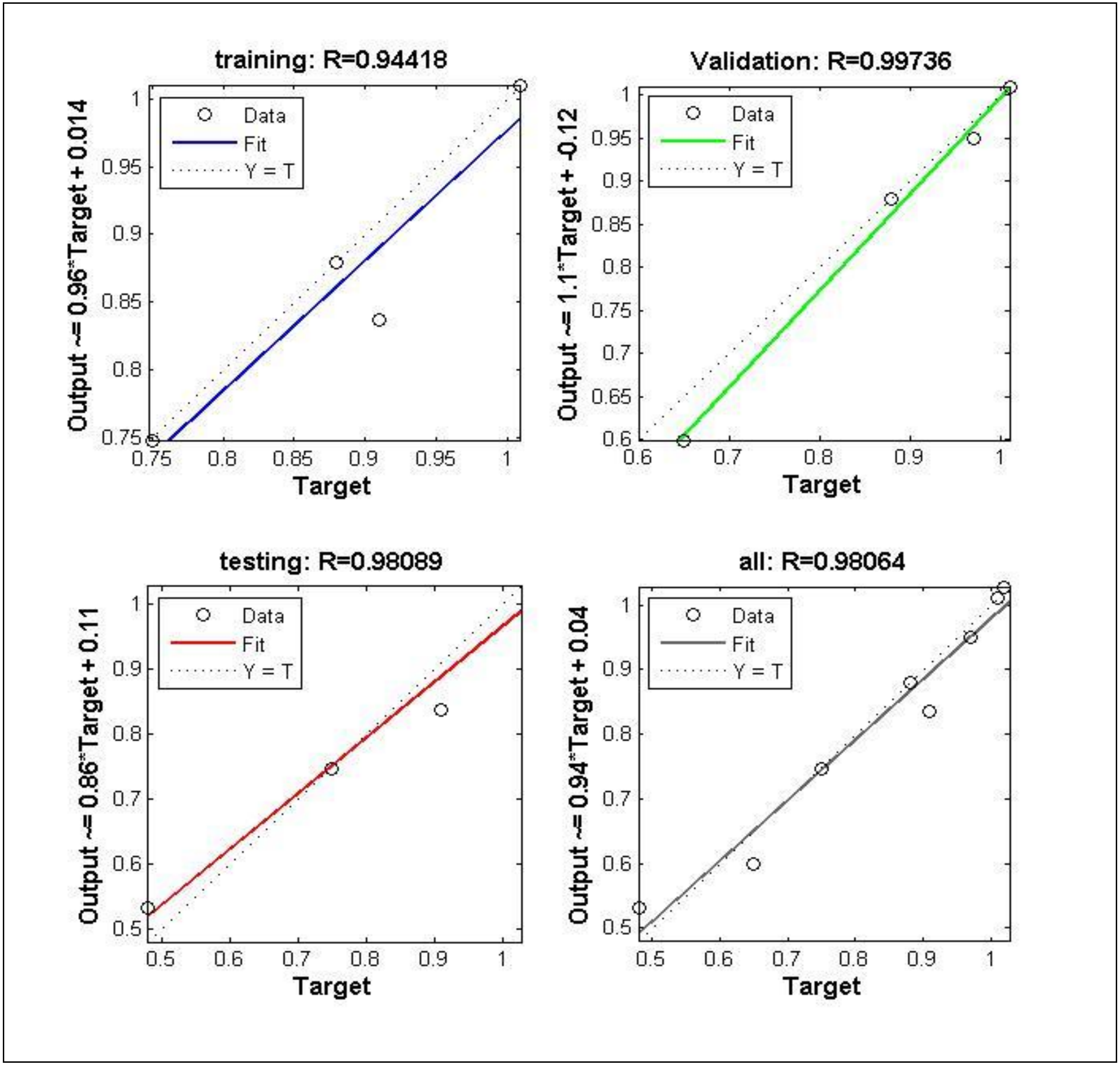


Figure 5.33: Performance of ANN (PCs) for Motorized Trip Rate-CA2

From the Figure 5.33, it is observed a negative deviation (from threshold value of 1) in slope of solid line for training and testing data set. A positive deviation of the same for validation data set. The overall correlation coefficient is 0.98 and mean square error is zero, as given in Table 5.42.

Table 5.42: Training Results of the ANN (PCs)-Motorized Trip Rate-CA2

Back Propagation with Trainlm (PCs)		
Overall (R)	MSE	Epochs
0.980	0.000	2

5.14.3 ANN Model with PCs of CA3 Category of Cities

Five Principal Components Data of cities with city area more than 1000 sq.km were taken for ANN process. Performance of training, validation, and testing for the network with total inputs and Trip rate as output are presented in Figure 5.34. Training results like R-value and Mean Square Error (MSE) are given in Table 5.43.

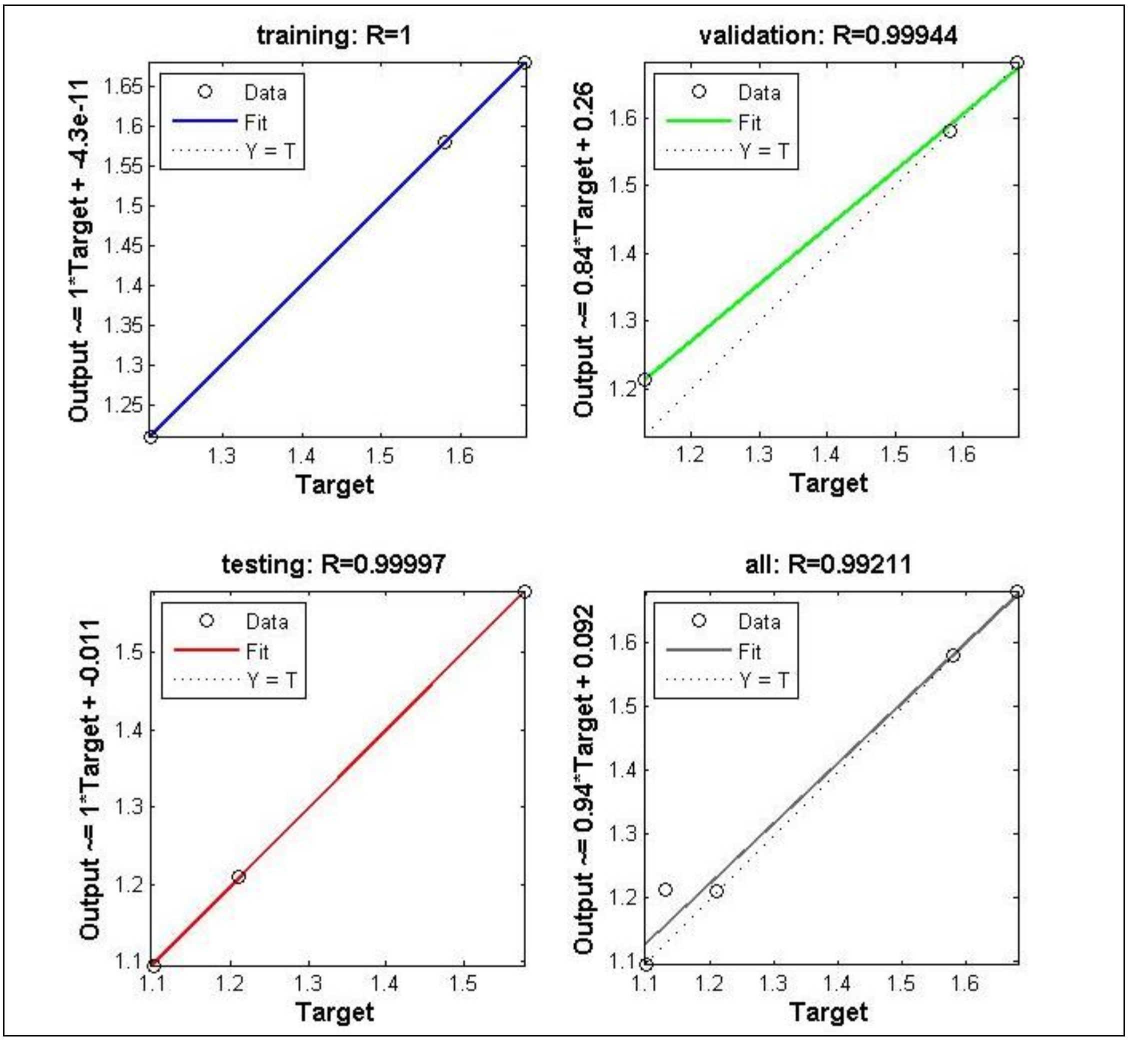


Figure 5.34: Performance of ANN (PCs) for Trip Rate-CA3

From the Figure 5.34, the network outputs are well estimated for training and testing data set. However, there is a deviation in the estimation of the same for validation data set. The overall correlation coefficient is 0.99 and mean square error at 4th iteration is 0.002, as presented in Table 5.43.

Table 5.43: Training Results of the ANN (PCs)-Trip Rate-CA3

Back Propagation with Trainlm (PCs)		
Overall (R)	MSE	Epochs
0.992	0.002	4

PCA and ANN for Motorized Trip Rate of CA3 Category of Cities:

Five Principal Components Data of cities was processed similarly for Motorized Trip Rate. The findings are presented in Figure 5.35 and Table 5.44.

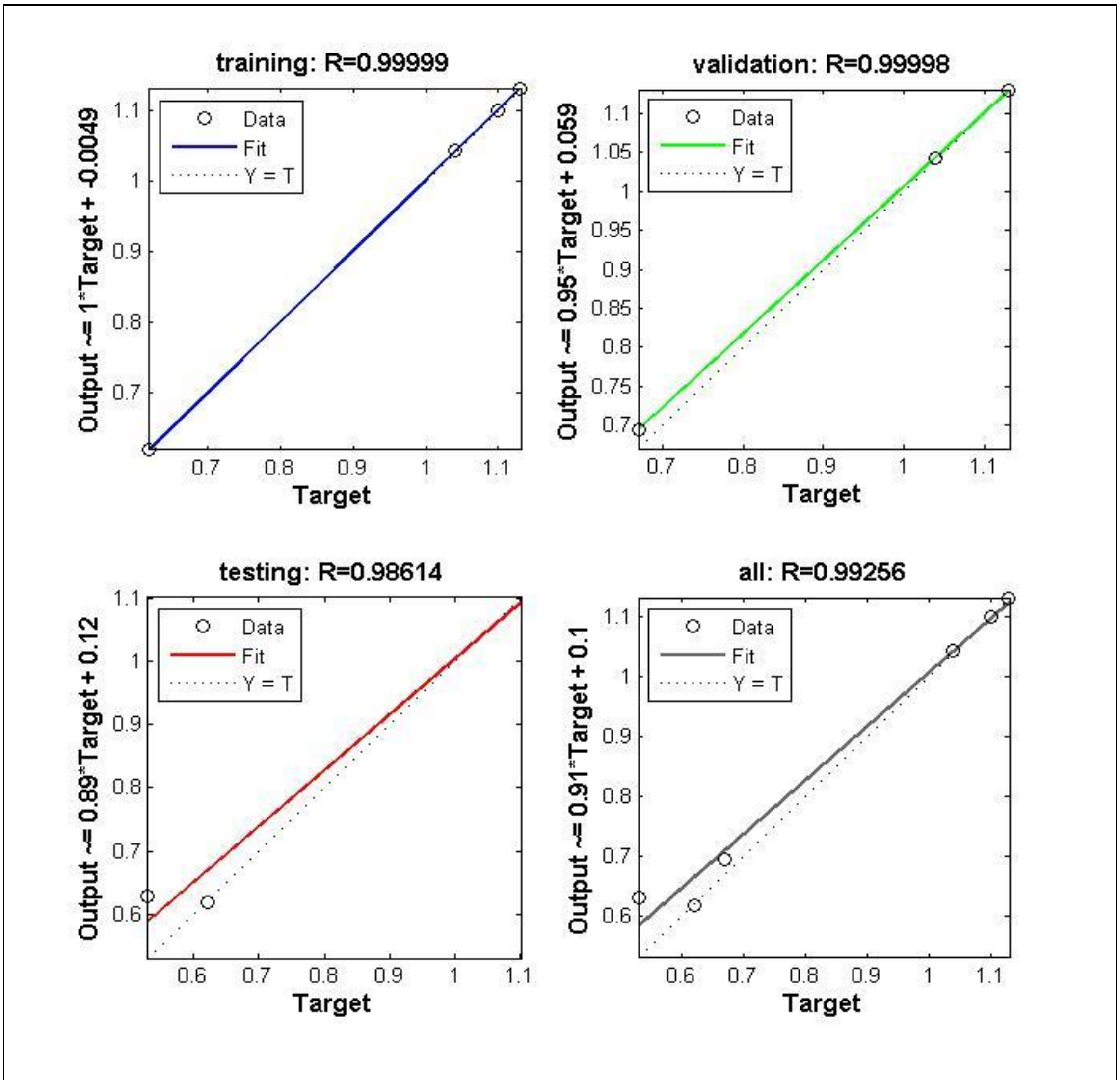


Figure 5.35: Performance of ANN (PCs) for Motorized Trip Rate-CA3

From the Figure 5.35, training data set has better estimation of network outputs. However, there exists a minor estimation of the same for validation and testing data sets. The overall correlation coefficient is 0.99 and mean square error is zero, as shown in Table 5.44.

Table 5.44: Training Results of the ANN (PCs)-Motorized Trip Rate-CA3

Back Propagation with Trainlm (PCs)		
Overall (R)	MSE	Epochs
0.992	0.000	2

Summary of ANN Model Results- City Area Category & PC as Input:

Out of three categories of cities based on population, ANN model with CA1, Principal Component as input yield better results. For Trip Rate, Overall Correlation Coefficient for this category is 0.99 with mean square error (MSE) of zero. Motorized trip rate has Overall Correlation Coefficient of 0.99 and mean square error (MSE) of zero for CA3 categories of cities.

5.15. Comparison of ANN Models - With Original Data and Principal Components

The performance of ANN models for various categories is given in Table 5.45. It is observed that R-values and mean square errors were improved by categorisation of cities data based on population and city area except for CP2. R-value and mean square errors were bettered by the application of principal components as input to ANN except for CP2.

Table 5.45: Performance of ANN for Various Data Combinations

Category	Original data as Input to ANN					PC DATA				
	Network Structure	Trip Rate		Motorized Trip Rate		Network Structure	Trip Rate		Motorized Trip Rate	
		R-Value	MSE	R-Value	MSE		R-Value	MSE	R-Value	MSE
All Cities Data										
ALL	20:20:1	0.95	0.015	0.96	0.014	5:5:1	0.96	0.002	0.97	0.003
Cities Data Categorized Based On City Population										
CP1	20:20:1	0.99	0.000	0.96	0.000	5:5:1	0.99	0.000	0.99	0.000
CP2	20:20:1	0.97	0.001	0.89	0.000	5:5:1	0.66	0.000	0.92	0.004
CP3	20:20:1	0.91	0.004	0.92	0.002	5:5:1	0.98	0.001	0.93	0.001
Cities Data Categorized Based On City Area										
CA1	20:20:1	0.99	0.000	0.95	0.002	5:5:1	0.99	0.000	0.98	0.001
CA2	20:20:1	0.96	0.039	0.96	0.034	5:5:1	0.97	0.001	0.98	0.000
CA3	20:20:1	0.99	0.000	0.98	0.004	5:5:1	0.99	0.002	0.99	0.000

From the above results, ANN models with Principal Components are found to be having better performance compared to ANN with original (Socio-economic and Land Use) data.

5.16. Summary

This chapter dealt with development of regression models for original and categorised cities data. Regression models were also developed with principal components. For ANN models formulation, training function for ANN is selected. Trip rate and motorized trip rate prediction models using ANN for original and categorized data were developed. Models were also formed with principal component inputs using ANN for original and categorized data. Performance of all these models were summarized in this chapter.

Chapter 6

Development of Nomograms for Trip Rate

6.1. Introduction

Models were developed on the data for various categories of cities based on population and city area in the previous chapter. For instant estimation of Trip Rate, Nomograms are necessary. Pynomo software, used for developing Nomograms, description and working procedure will be discussed in this chapter. Nomograms created will be presented for various city categories.

6.2. Nomograms

A Nomogram is a sketch useful for calculating a variable graphically, which is supposed to be calculated by the mathematical formula. Sometimes called an alignment chart, a nomogram consists of a set of numbered scales, usually one for each variable in the formula, arranged so that a straightedge can be placed across known values to find the unknown value that solves the formula. Since an equation in two variables is usually represented by a graph, most nomograms represent formulas that involve three or more variables. These graphical calculators were invented in 1880 by Philbert Maurice d'Ocagne and used extensively for many years to provide engineers with fast graphical calculations of complicated formulas to a practical precision. There are 10 different general types of nomograms, including the most common one of 3 parallel scales for addition or multiplication, "N" or "Z" for division, proportions, sum of reciprocals, and so forth. It can also handle general determinant forms, even with more than 3 variables, so it can really handle any type of nomogram. Terms associated with Nomograms are presented in Figure 6.1.

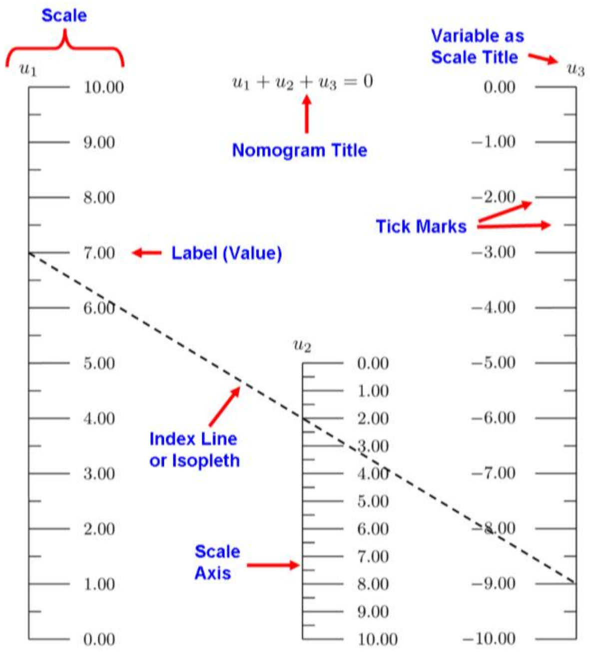


Figure 6.1: Terms associated with Nomogram

6.3. Pynomo Software

Pynomo software is used for the creation of Nomograms. Leif Roschier (2008) is the creator of this software. The output of these programs will be in PDF or EPS files. Pynomo supports ten basic types of Nomograms with different program scripts. Pynomo is a good tool for drawing Nomograms. The types of Nomograms supported by Pynomo is given in Table 6.1.

Table 6.1: Nomograms Types Supported by Pynomo

Type	Form of Equation	Form of Nomogram
Type 1	$f_1(u_1)+ f_2(u_2)+ f_3(u_3)= 0$	3 Parallel Scales
Type 2	$f_1(u_1)= f_2(u_2)\times f_3(u_3)$ or $f_3(u_3)= f_1(u_1)/ f_2(u_2)$	N or Z
Type 3	$f_1(u_1)+ f_2(u_2)+...+ f_n(u_n)= 0$	Compound Parallel Scales
	$f_1(u_1)+ f_2(u_2)+ f_3(u_3)= 0$ and $f_3(u_3)+ f_4(u_4)+ f_5(u_5)= 0$	3 Parallel Scales Compounded
Type 4	$f_1(u_1) /f_2(u_2) = f_3(u_3)/ f_4(u_4)$	Proportion
Type 5	$f_1(v)= f_2(x,u)$	Contour
Type 6	u = u	Ladder
Type 7	$1/ f_3(u_3) = 1 /f_1(u_1) + 1/ f_2(u_2)$	Reciprocal/Angle
Type 8	y = f(u)	Single Scale
Type 9	Determinant	General Nomogram
Type 10	$f_1(u)+ f_2(v)f_3(w)+ f_4(w)= 0$	One Curved Line

6.4. Development of Nomogram

Nomograms for the present study were created based on the models formed in chapter 5. These models were developed for various categories of cities based on population and area as explained in the previous chapter.

Input variables like land-use data, socio-economic data variables are considered for studying trip rate. Socio-economic variables considered are Population, Area, Population Density, Per capita Income (Rs), City Buses (Nos), Road Safety Index, Male (%), Female (%) and Registered vehicles (Nos). Land-Use variables considered are Residential(%), Commercial(%), Industrial(%), Public(%), Recreational(%) and Transport(%).

Models for trip rate and Motorized trip for various city categories based on population and city area are given in Tables 6.2 to 6.5. There are two types of models developed. First one is with one independent variable and the second one is with two independent variables.

Table 6.2: Models considered for Nomograms for Trip Rate-City Category based on Population

<table>
<tr><th></th><th colspan="2">Trip Rate</th></tr>
<tr><th>Category</th><th>Single Input Variable Models</th><th>Two Input Variables Models</th></tr>
<tr><td rowspan="3"><10 Lakhs</td><td>Trip Rate=0.0005*Area + 0.808</td><td rowspan="3">Trip Rate=0.0146*Population + 0.000151*Area + 0.787</td></tr>
<tr><td>Trip Rate=0.0188*Population + 0.789</td></tr>
<tr><td>Trip Rate=0.000439*Registered Vehicles+0.787</td></tr>
<tr><td rowspan="2">10-40 Lakhs</td><td>Trip Rate=0.011*Population + 0.928</td><td rowspan="2">Trip Rate=0.0108*Population + 0.000103*City Buses + 0.928</td></tr>
<tr><td>Trip Rate=0.00021*City Buses + 1.121</td></tr>
<tr><td rowspan="4">>40 Lakhs</td><td>Trip Rate= 0.0000797*Area + 1.372</td><td rowspan="4">Trip Rate=0.0000294*City Buses + 0.000061*Area + 1.31

Trip Rate=0.000482*PerCapita Income + 0.0000356*City Buses +1.316</td></tr>
<tr><td>Trip Rate=0.0024*Population +1.228</td></tr>
<tr><td>Trip Rate=0.000643*Per Capita Income + 1.401</td></tr>
<tr><td>Trip Rate=0.0000435*City Buses+1.344</td></tr>
</table>

Table 6.3: Models considered for Nomograms for Motorized Trip Rate-City Category based on Population

	Motorized Trip Rate	
Category	**Single Input Variable Models**	**Two Input Variables Models**
<10 Lakhs	Motorized Trip Rate=0.0174*Population + 0.370	• Motorized Trip Rate=0.017* Industrial Area + 0.000318* Registered Vehicles + 0.354 • Motorized Trip Rate=0.017*Population + 0.00074*Industrial Area + 0.371
	Motorized Trip Rate=0.000402*Registered Vehicles + 0.370	
	Motorized Trip Rate=0.0314*Industrial Area + 0.401	
10-40 Lakhs	Motorized Trip Rate=0.0000109*Population Density + 0.539	Motorized Trip Rate=9x10^{-5}*Population Density + 2x10^{-4}*City Buses+0.518
	Motorized Trip Rate=0.000344*City Buses + 0.566	
>40 Lakhs	Motorized Trip Rate=0.002*Population + 0.775	• Motorized Trip Rate=0.0014*Population +1.7x10^{-5}* City Buses+0.782 • Motorized Trip Rate=0.0018*Population + 5x10^{-6}* Registered Vehicles+0.775
	Motorized Trip Rate=4.4x10^{-5}*City Buses + 0.850	
	Motorized Trip Rate=2.8x10^{-5}*Registered Vehicles + 0.875	

Table 6.4: Models considered for Nomograms for Trip Rate-City Category based on City Area

	Trip Rate	
Category	**Single Input Variable Models**	**Two Input Variables Models**
<300 sq.km	Trip Rate= 0.018*Population + 0.795	• Trip Rate= 0.0169*Population +5x10^{-5}* Registered Vehicles + 0.79 • Trip Rate= 3.7x10^{-3}*Per Capita Income +2.3x10^{-4}* Registered Vehicles+0.761
	Trip Rate= 1.8x10^{-5}*Population Density + 0.883	
	Trip Rate= 0.0065*Per Capita Income + 0.735	
	Trip Rate= 4.2x10^{-4}*Registered Vehicles + 0.851	
300-1000 sq.km	Trip Rate= 0.0057*Population + 1.002	• Trip Rate= 0.0046*Population +6.4x10^{-6}*Population Density + 0.996 • Trip Rate= 1.9x10^{-5}*Population Density + 3.9x10^{-5}*City Bus + 1.053 • Trip Rate= 1.8x10^{-5}*Population Density +4.5x10^{-5}* Register Vehicles
	Trip Rate= 2.4x10^{-5}*Population Density + 1.057	
	Trip Rate= 9.4x10^{-5}*Registered Vehicles + 1.108	
	Trip Rate= 8.07x10^{-5}*City Buses + 1.197	

	Trip Rate	
Category	**Single Input Variable Models**	**Two Input Variables Models**
>1000 sq.km	Trip Rate= 0.0032*Population + 1.088	• Trip Rate= 6.7x10^{-5}*City Buses + 1.17x10^{-5}* Registered Vehicles + 1.180 • Trip Rate= 3.4x10^{-5}*Population Density + 2.4x10^{-5}* Registered Vehicles + 1.163
	Trip Rate= 4.8x10^{-5}*Population Density + 1.178	
	Trip Rate= 7.8x10^{-5}*City Buses + 1.187	
	Trip Rate= 5.02x10^{-5}*Registered Vehicles + 1.229	

Table 6.5: Models considered for Nomograms for Motorized Trip Rate-City Category based on City Area

	Motorized Trip Rate	
Category	**Single Input Variable Models**	**Two Input Variables Models**
<300 sq.km	Motorized Trip Rate =1.9x10^{-5}*Population Density+0.39	• Motorized Trip Rate =1.6x10^{-5}*Population Density +2.6x10^{-4}* City Buses+0.378
	Motorized Trip Rate =0.0043*Per Capita Income + 0.358	
	Motorized Trip Rate = 5.4x10^{-4}*City Buses+0.481	
300-1000 sq.km	Motorized Trip Rate =0.0063*Population + 0.488	• Motorized Trip Rate =1.6x10^{-5}*Population Density + 6.3x10^{-5}*City Buses + 0.576 • Motorized Trip Rate = 1.2x10^{-5}*City Buses + 9.7x10^{-5}*Registered Vehicles + 0.601 • Motorized Trip Rate = 1.3x10^{-5}*Population Density +7.3x10^{-5}* Registered Vehicles+0.533
	Motorized Trip Rate =2.41x10^{-5}*Population Density + 0.582	
	Motorized Trip Rate =9.5x10^{-5}*City Buses + 0.694	
	Motorized Trip Rate =1.09x10^{-4}*Registered Vehicles + 0.593	
>1000 sq.km	Motorized Trip Rate =0.0033*Population + 0.548	• Motorized Trip Rate = 0.003*Population +6.9x10^{-6}* Population Density+0.547 • Motorized Trip Rate =0.0029*Population + 1.01x10^{-5}*City Buses+0.552 • Motorized Trip Rate =7.2x10^{-5}*City Buses + 1.26x10^{-5}*Register Vehicles + 0.633 • Motorized Trip Rate =3.8x10^{-5}*Population Density + 2.5x10^{-5}*Register Vehicles+0.612
	Motorized Trip Rate =5.2x10^{-5}*Population Density + 0.628	
	Motorized Trip Rate =8.4x10^{-5}*City Buses + 0.64	
	Motorized Trip Rate =5.4x10^{-5}*Registered Vehicles + 0.686	

Type 8 Nomograms scripts were used to form the single input variable Nomograms. Whereas, for two input variables, Type 1 Nomogram scripts were used.

Methodology Adopted:

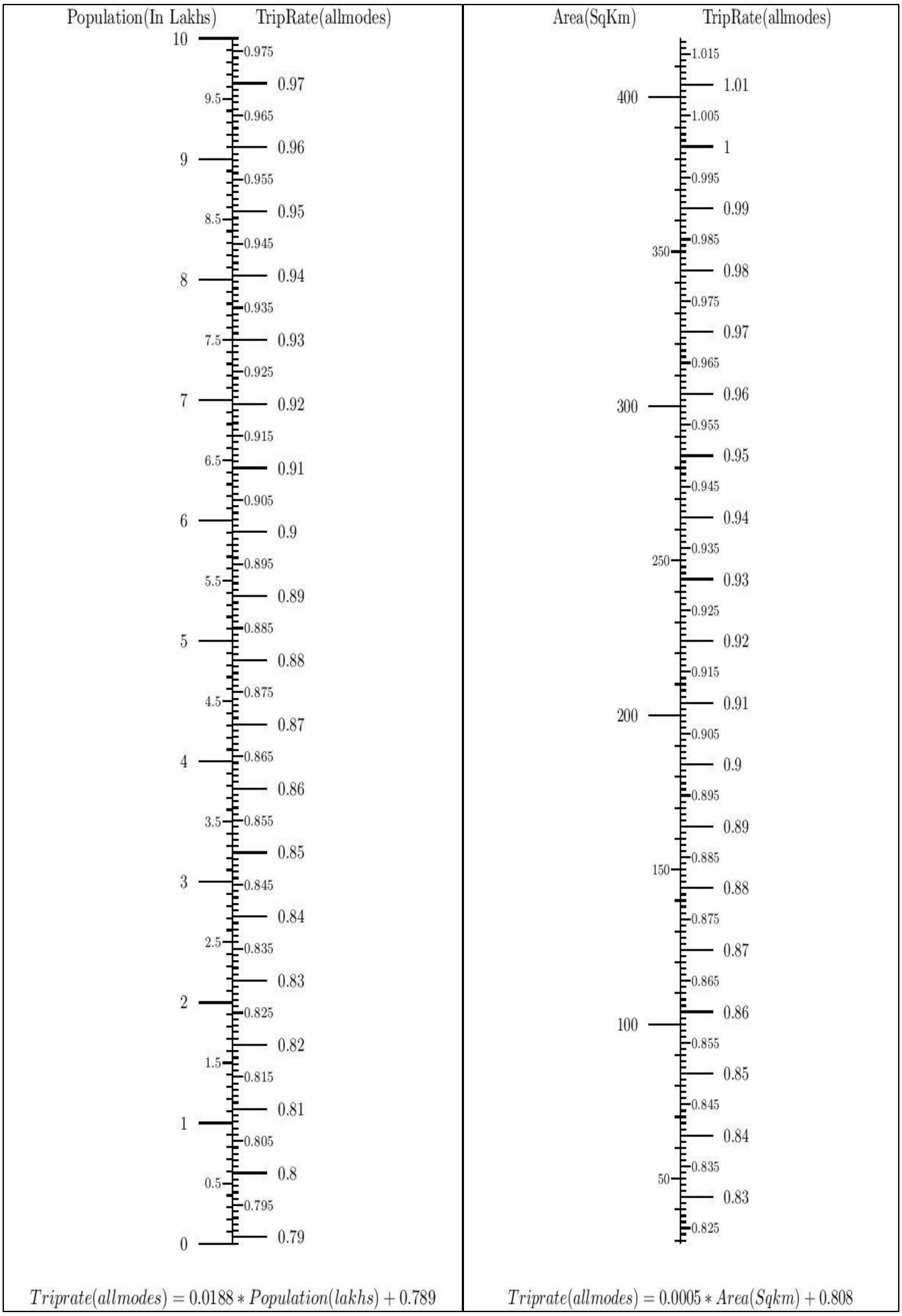
1. Available data based on Population and City Area criteria were categorised.
2. Correlation matrices for the categorized data (for both Population and City Area Criteria) was formed
3. Variables which are in good relation with Trip Rate and Motorized Trip Rate were identified.
4. Models for Trip Rate and Motorized Trip Rate with those selected variables (1 and 2 variable case) were developed.
5. Script of Type 8 Nomogram was altered to get Nomogram for single variable case. Script of Type 1 Nomogram was altered to get Nomogram for two variable case.

6.5. Nomograms for Trip Rate for City Categories Based On Population

6.5.1. City Category -CP 1 (Population <10 lakhs)

Single Input Variable Case:

In this category, various variables, which influence with trip rate are population , Area and Registered vehicles. Nomograms of Trip Rate with these variables are given in following Figures 6.2 and 6.3.



(a) (b)

Figure 6.2: Nomograms for Trip Rate -Population and Area - CP1

Example: (i) For Population = 5 lakhs, Trip Rate = 0.883 (From Figure 6.2(a))

(ii) For City Area = 100 sqkm, Trip Rate = 0.858 (From Figure 6.2(b))

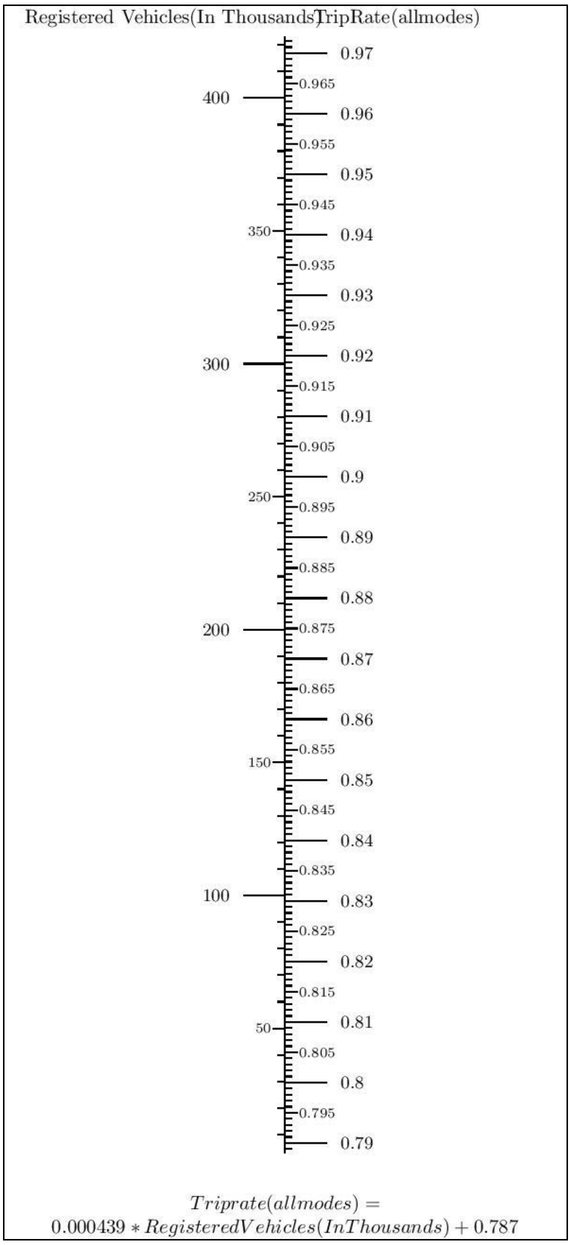


Figure 6.3: Nomograms for Trip Rate-Registered Vehicles - CP1

Example: Registered Vehicles (In thousands) = 300, Trip Rate = 0.917

Two Input Variables Case:

The following are the various variable combinations used in the preparation of Nomogram for cities of population less than 10Lakhs.

- Trip Rate Vs Population and Area

Nomograms prepared for these combinations are presented in the following Figures 6.4.

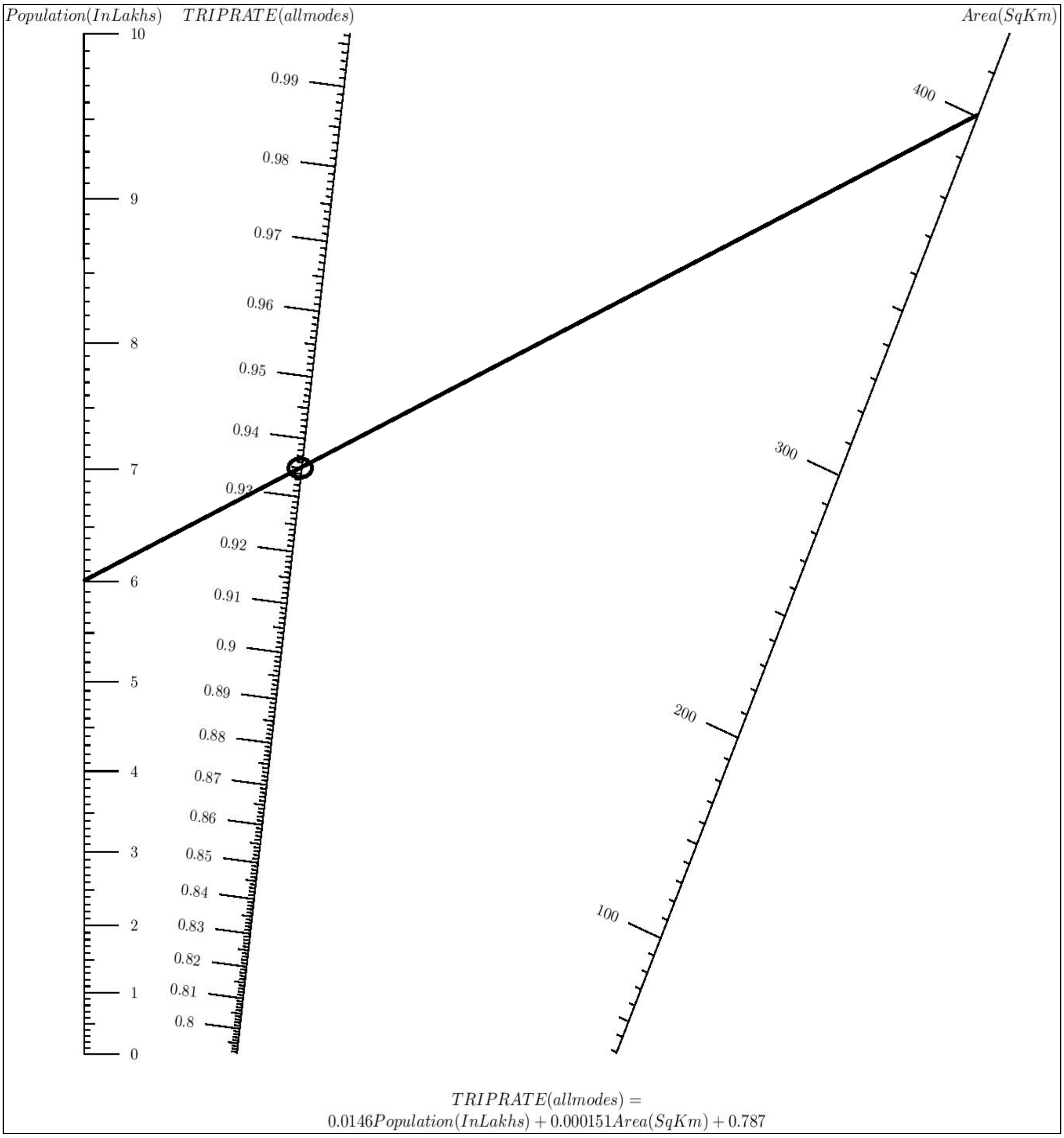


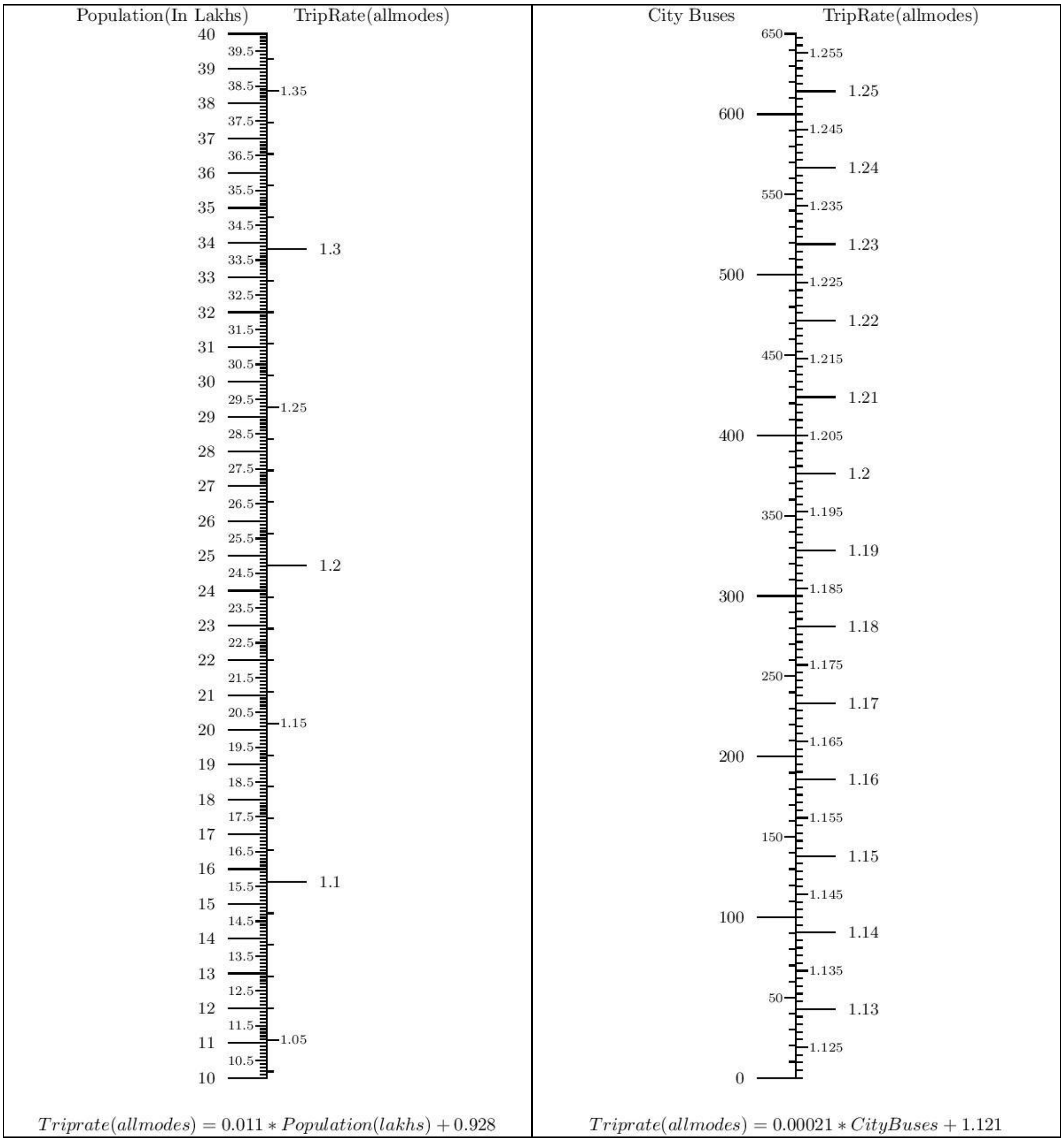
Figure 6.4: Nomogram between Trip Rate, Population and Area - CP1

Example: For Population (In Lakhs) = 6 and Area (Sqkm)= 400, then Trip Rate = 0.935

6.5.2. City Category -CP 2 (Population 10 - 40 lakhs)

Single Input Variable Case:

Taking cities of population ranging from 10 to 40 Lakh into account, Population and City buses influences Trip Rate. Plotted Nomogram with Trip Rate is presented in Figure 6.5.



(a) (b)

Figure 6.5 : Nomograms for Trip Rate -Population & City Buses - CP2

Example: Population (In Lakhs) = 20, Trip Rate = 1.148

City Buses (In Numbers) = 400, Trip Rate = 1.205

Two Input Variables Case:

For two input variable case with city data (whose population ranges from 10 to 40 Lakhs), the variables Population and City buses are proved better for estimating Trip Rate and same is used for Nomogram and presented in Figure 6.6.

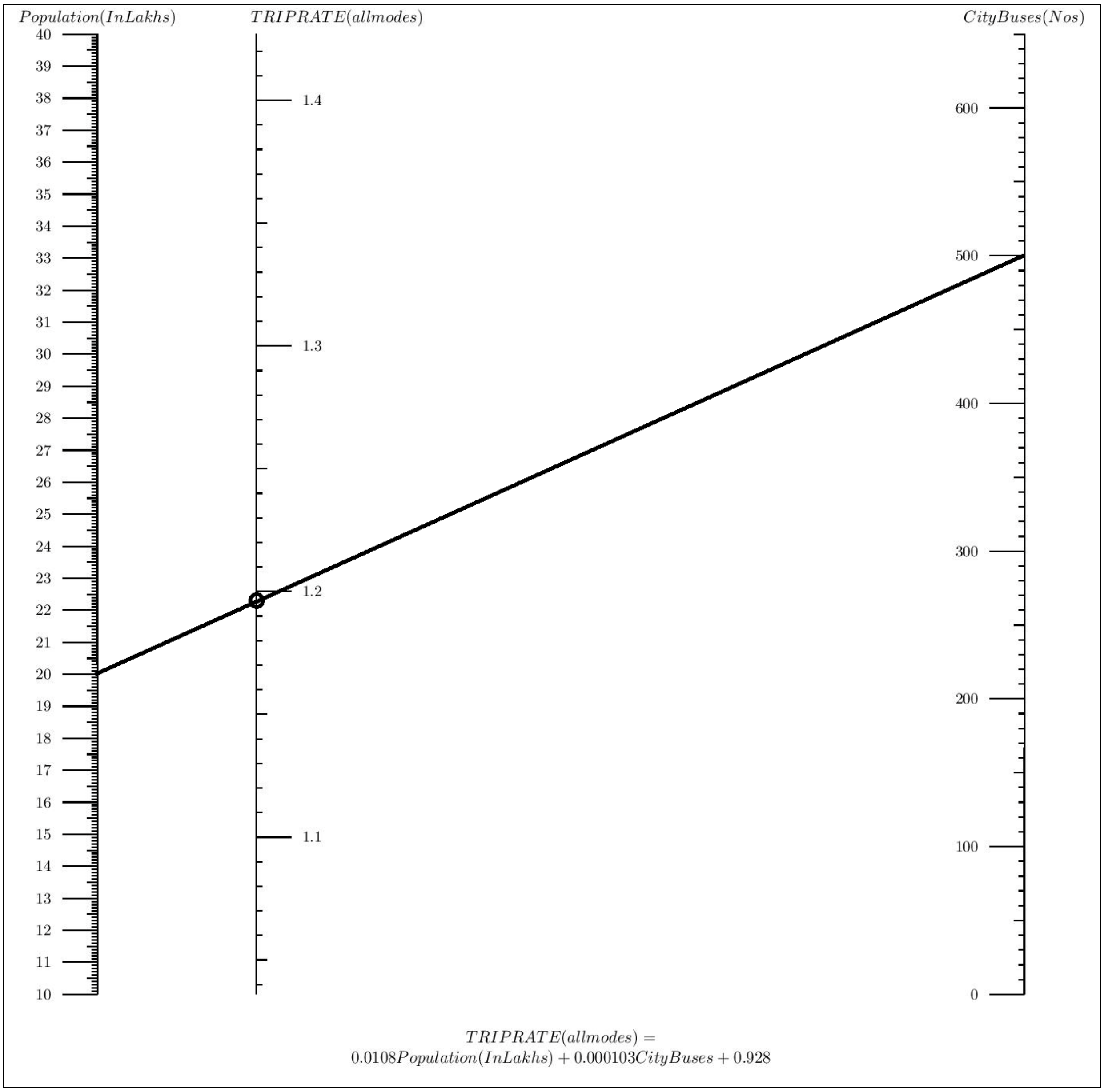


Figure 6.6: Nomogram for Trip Rate, Population and City Buses - CP2

Example: For Population (In Lakhs) = 20 and City Buses (In Numbers)= 500, then Trip Rate = 1.194

6.5.3. City Category -CP 3 (Population >40 lakhs)

Single Input Variable Case:

The variables of this case are Area, Population, Per Capita Income, and City Buses. The corresponding Nomograms are presented in the following Figures 6.7 and 6.8.

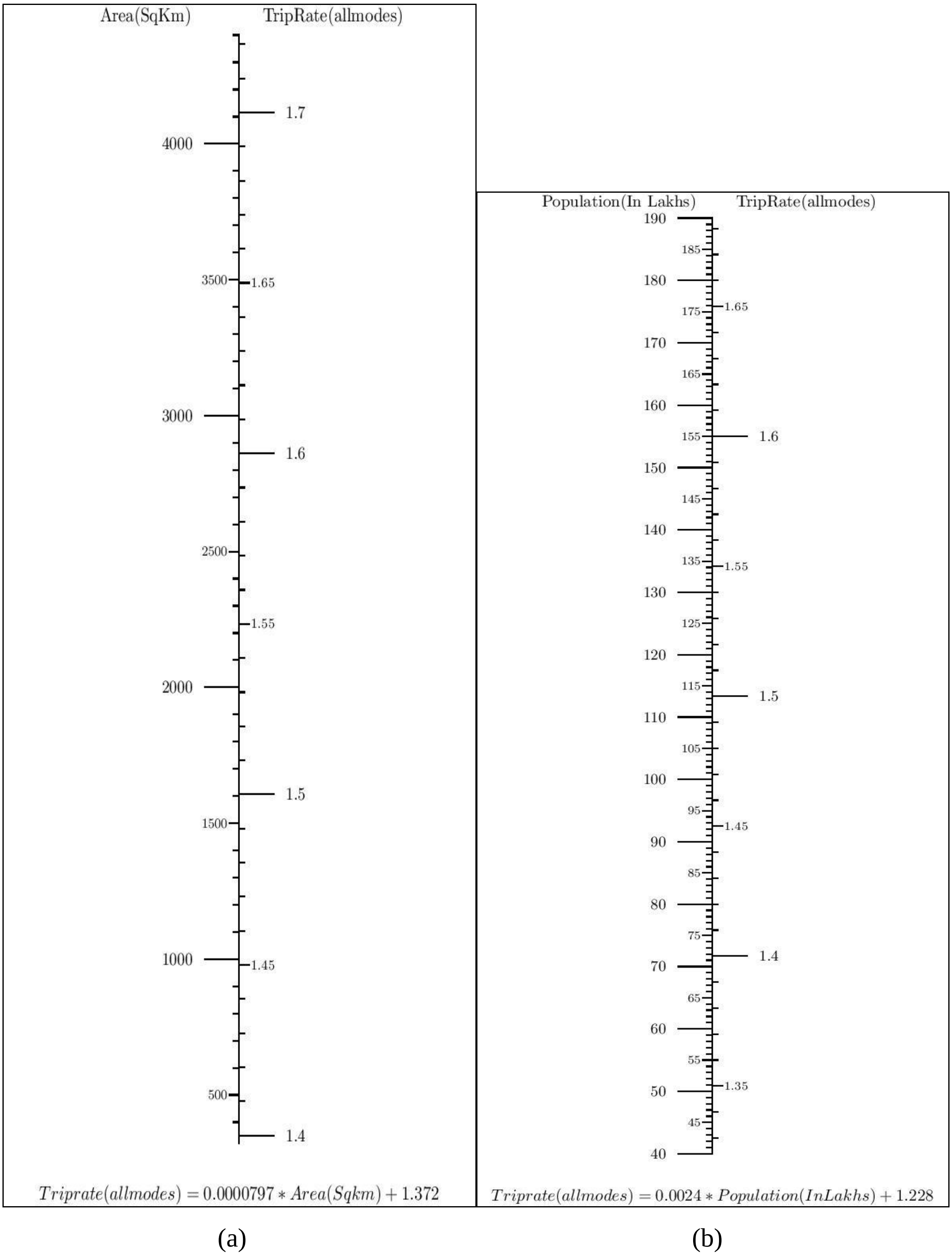
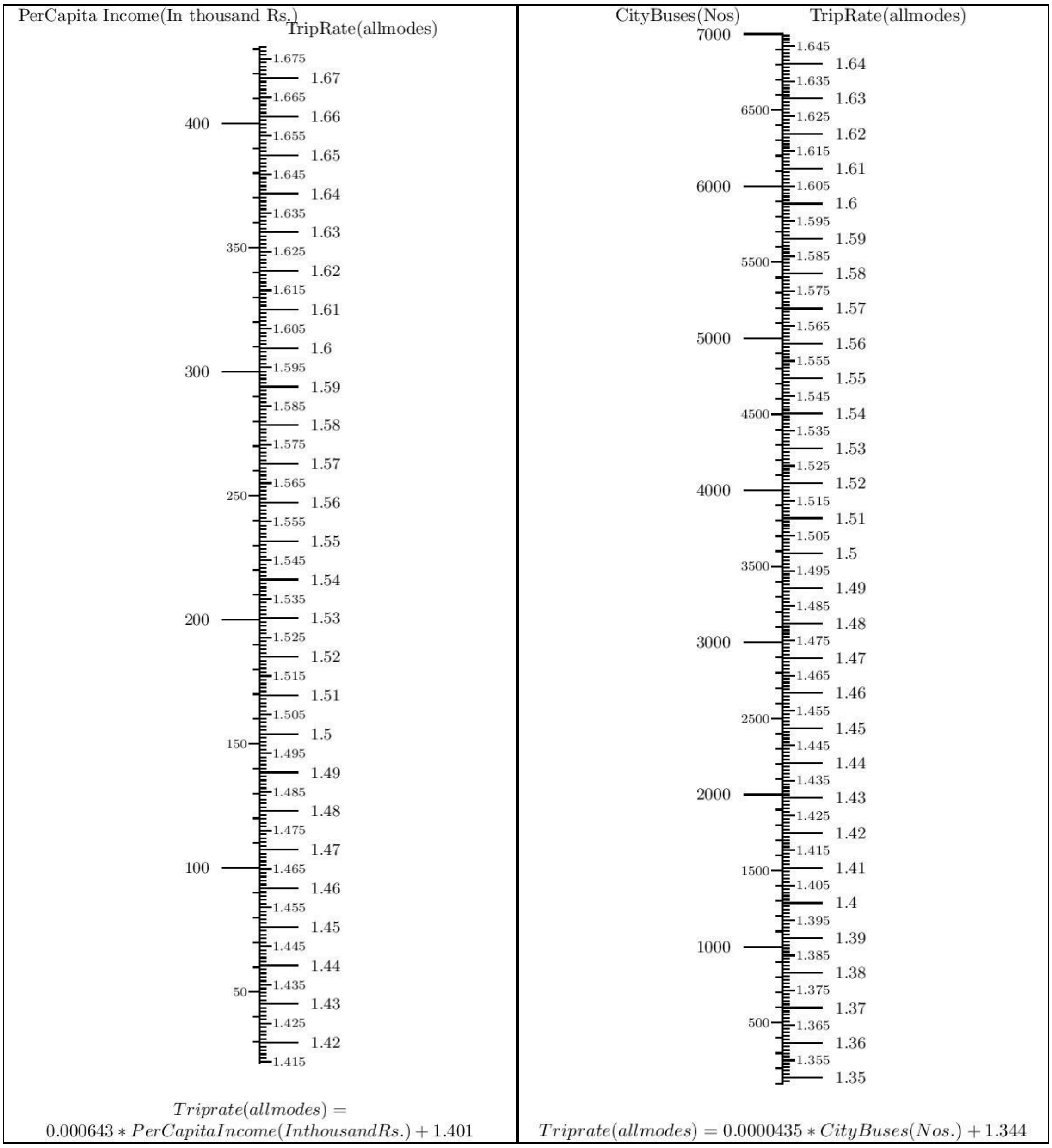


Figure 6.7: Nomograms for Trip Rate –Area and Population - CP3

Example: Area (SqKm) =3000, Trip Rate = 1.611 (From Figure 6.7(a))

Population (In Lakhs) = 100, Trip Rate = 1.468 (From Figure 6.7(b))



(a) (b)

Figure 6.8: Nomograms for Trip Rate-Per Capita Income and City Buses - CP3

Example: Per Capita Income (In thousands) =100, Trip Rate = 1.465 (From Figure 6.8(a))

City Buses (In Numbers) = 2000, Trip Rate = 1.432 (From Figure 6.8(b))

Two Input Variables Case:

The following are the various variable combinations used in the preparation of Nomogram for cities of population more than 40 Lakhs.

- Trip Rate Vs Area and City Buses

- Trip Rate Vs Per Capita Income and City Buses

The Nomograms for the above combinations are presented in Figures 6.9 and 6.10, respectively.

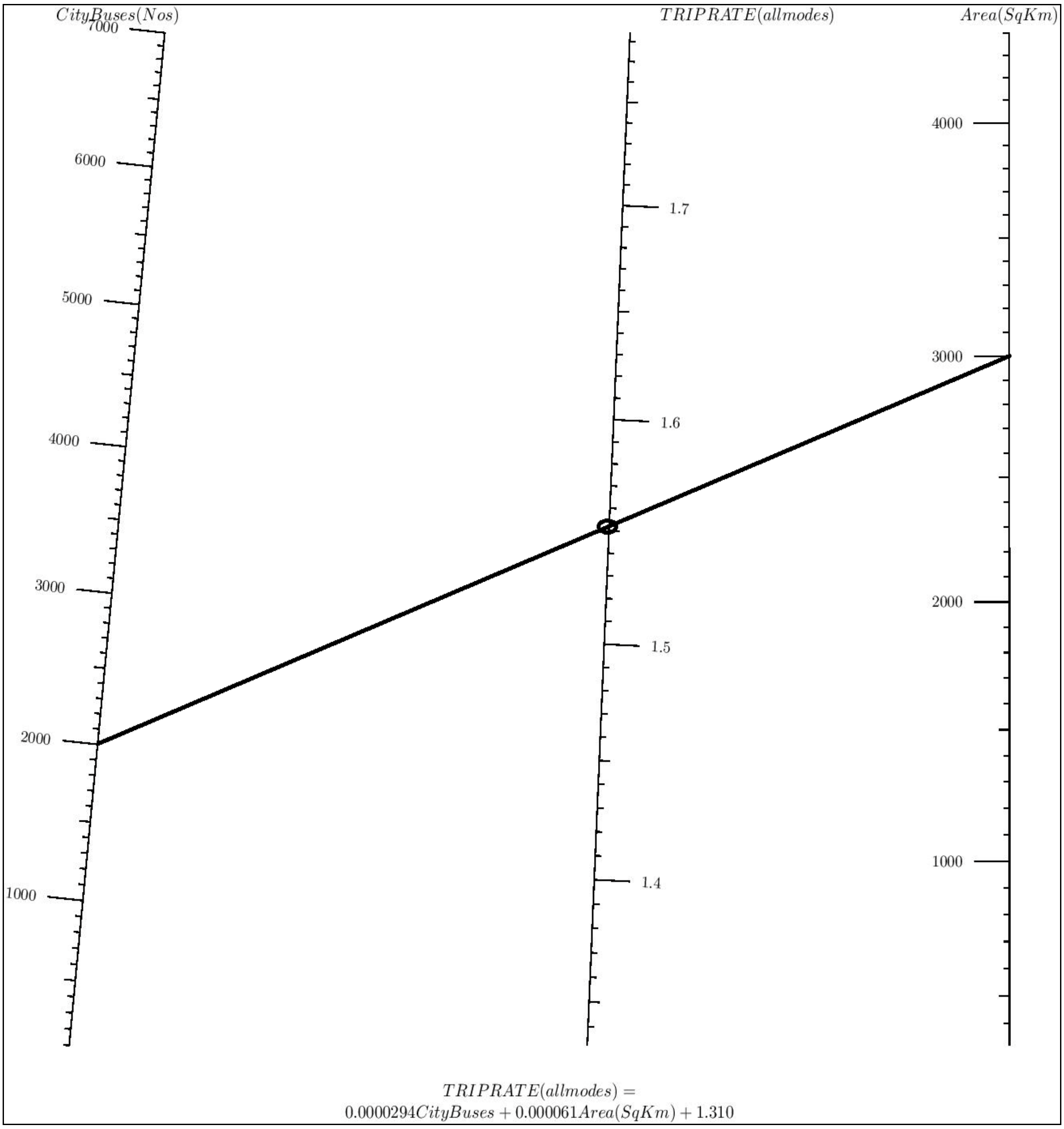


Figure 6.9: Nomogram for Trip Rate, City Buses and Area - CP3

Example: For City Buses (In thousands) = 2000 and Area (SqKm)= 3000, then Trip Rate = 1.55

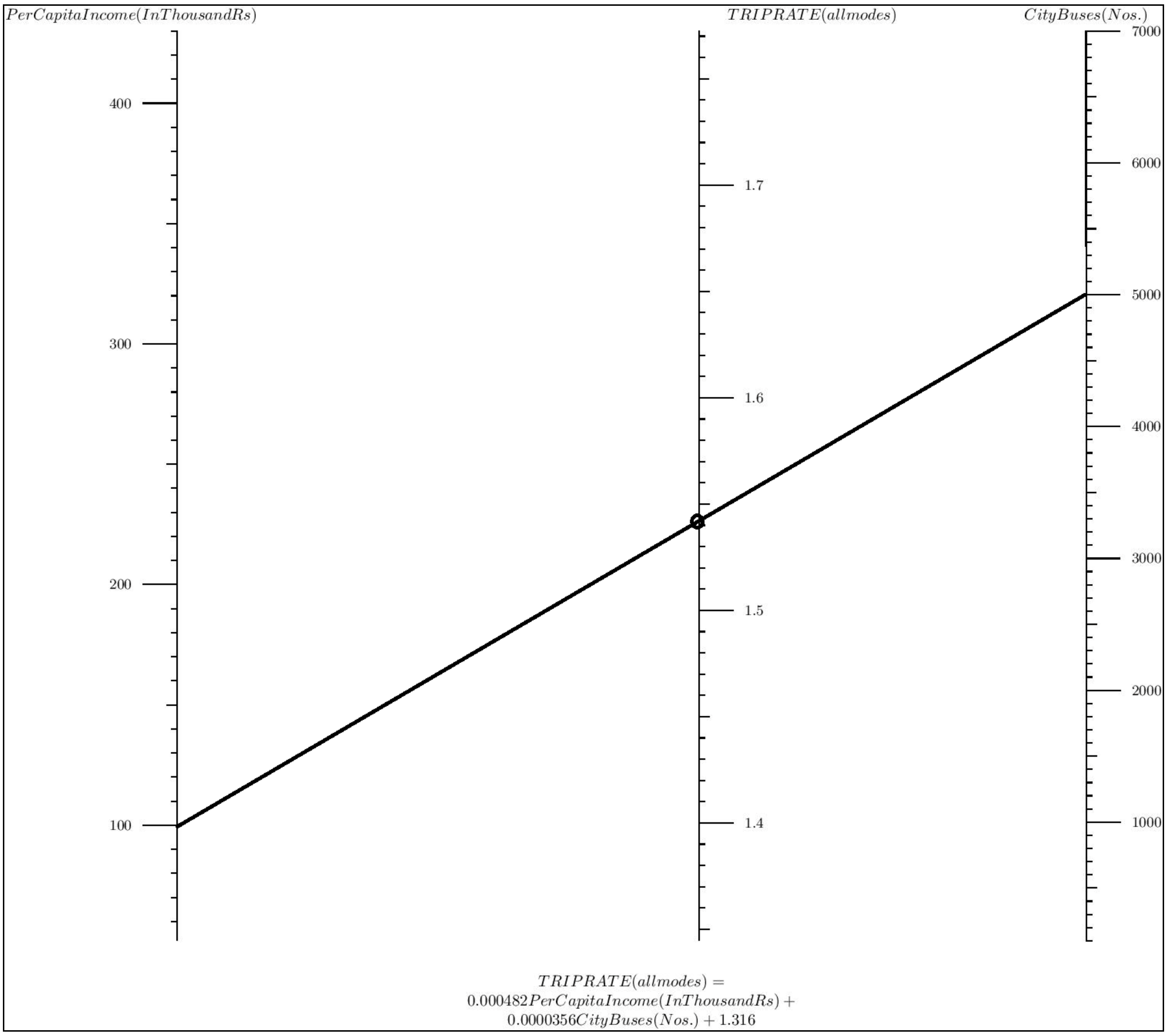


Figure 6.10: Nomogram for Trip Rate, Per Capita Income and City Buses - CP3

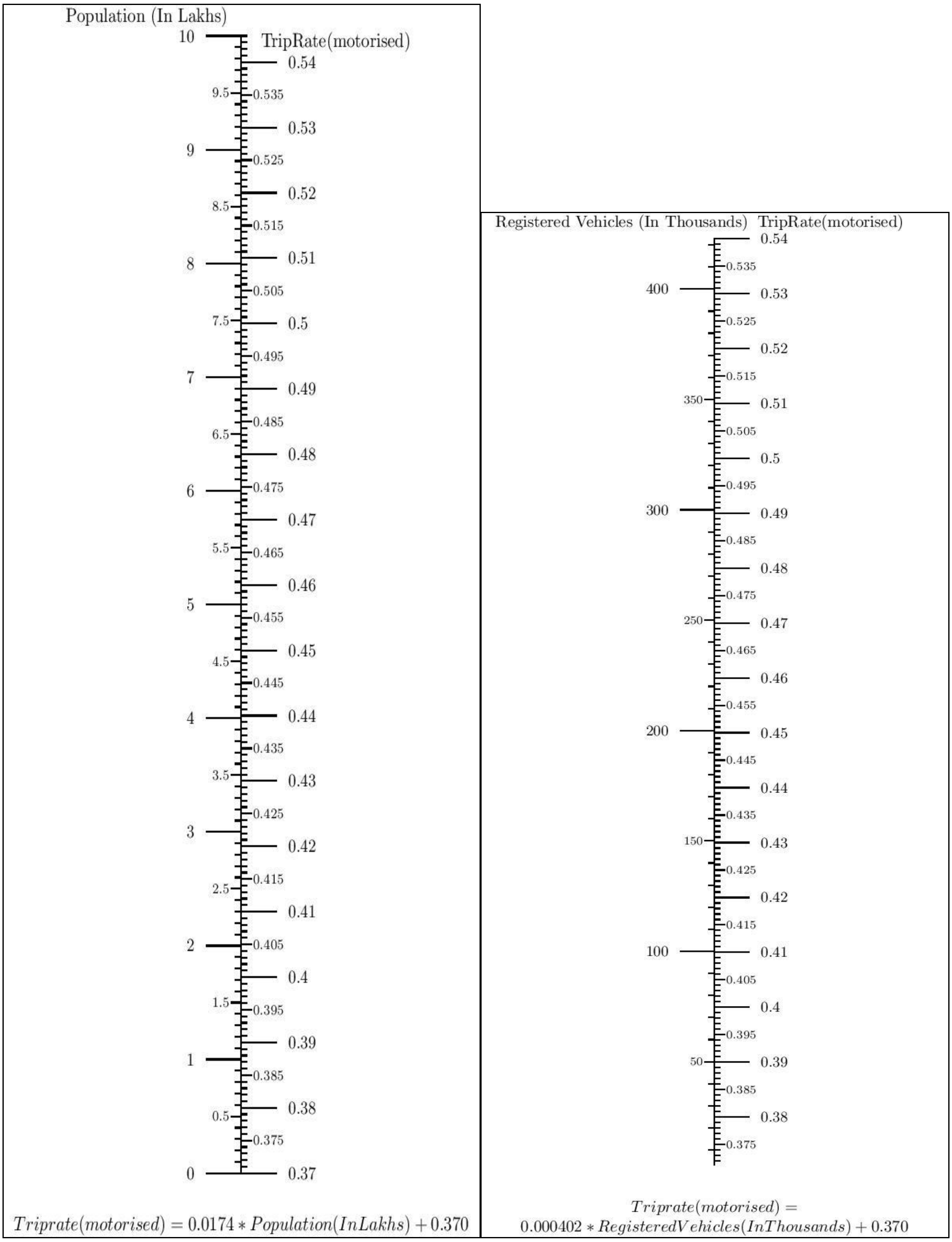
Example: For Per Capita Income (In thousands Rs.) = 100 and City Buses (In Numbers)= 5000, then Trip Rate = 1.54

6.6. Nomograms for Motorized Trip Rate -City Category Based On Population

6.6.1. City Category -CP 1 (Population <10lakhs)

Single Input Variable Case:

For smaller cities of population, less than 10 Lakhs, the variables like Population, Registered Vehicles and Industrial area (%) influences motorized Trip Rate, Individually. The Nomograms formed with these variables are presented below in Figures 6.11 and 6.12.



(a) (b)

Figure 6.11: Nomograms for Motorized Trip Rate-Population, Registered Vehicles - CP1

Example: Population (In Lakhs) =7, Trip Rate(motorised) = 0.492 (From Figure 6.11(a))

Registered Vehicles (In thousands) = 200, Trip Rate(motorised) = 0.451 (From Figure 6.11(b))

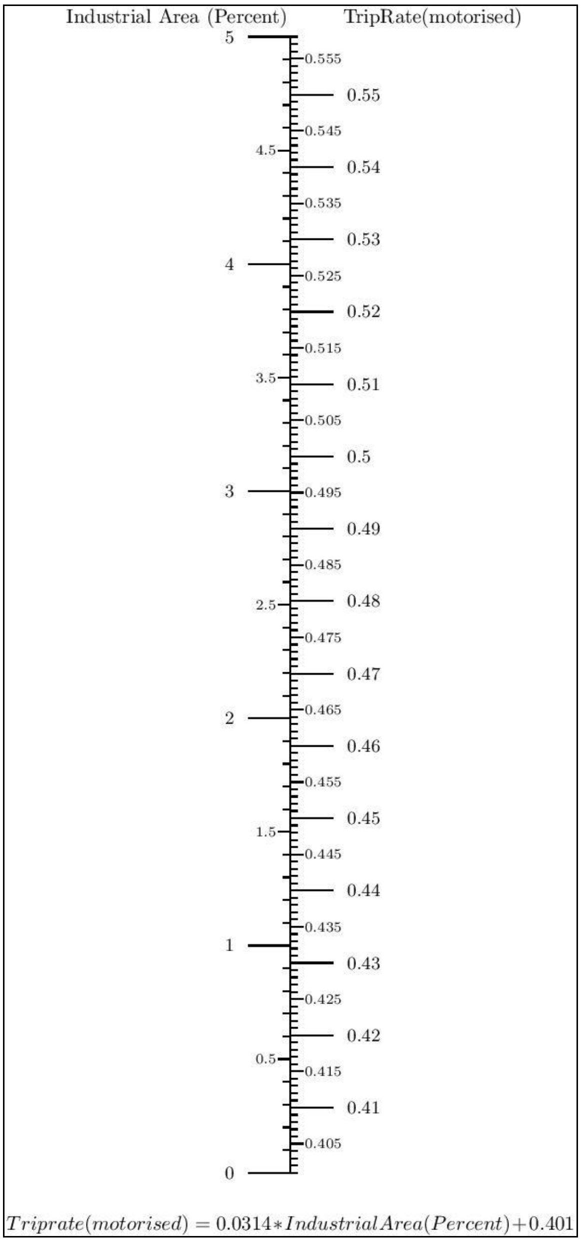


Figure 6.12: Nomograms for Motorized Trip Rate - Industrial Area - CP1

Example: Industrial Area (Percent) =3, Trip Rate(motorised) = 0.495

Two Input Variables Case:

The variables like City Population, Registered Vehicles and Industrial Area(%) influences Motorized Trip Rate for all cities with less than 10 Lakh population.

- Motorized Trip Rate Vs Registered Vehicles and Industrial Area(%)
- Motorized Trip Rate Vs Population and Industrial Area(%)

The Nomograms prepared with these combinations of variables are presented in the following Figures 6.13 and 6.14.

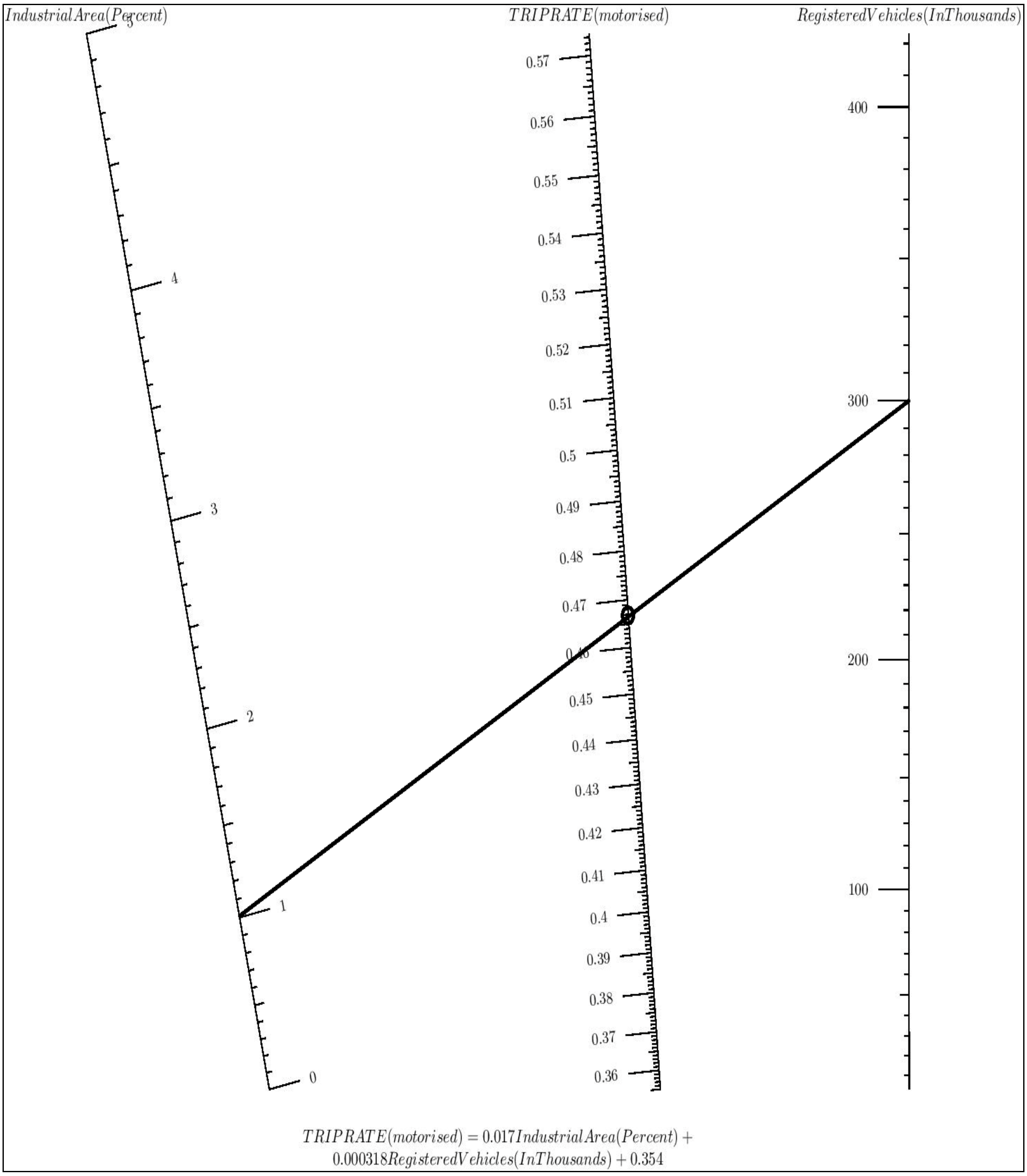


Figure 6.13: Nomogram for Motorized Trip Rate, Industrial Area and Registered Vehicle - CP1

Example: For Industrial Area (percent) = 1 and Registered Vehicles (In thousands)= 300, then Trip Rate (motorised) = 0.467

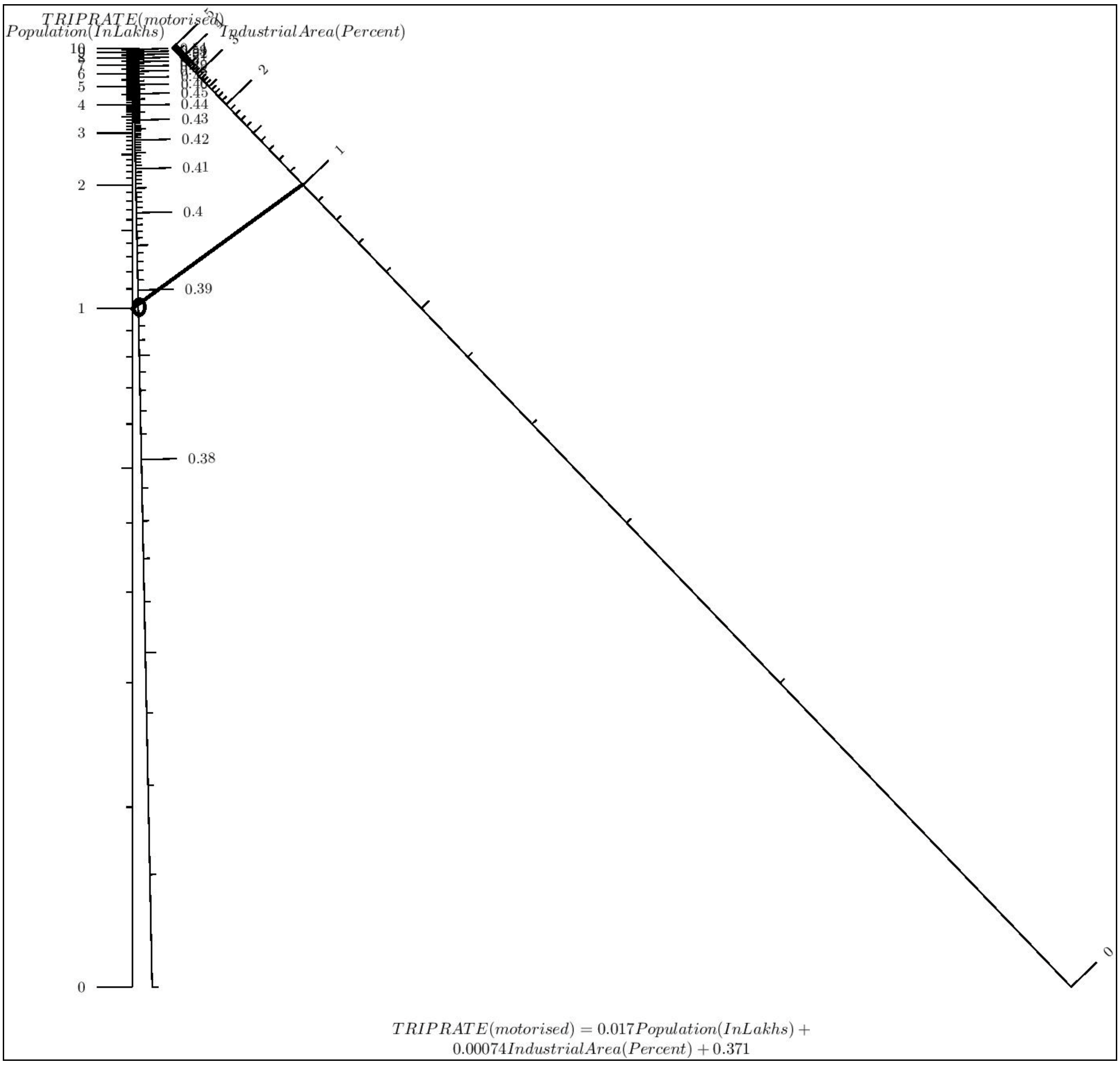


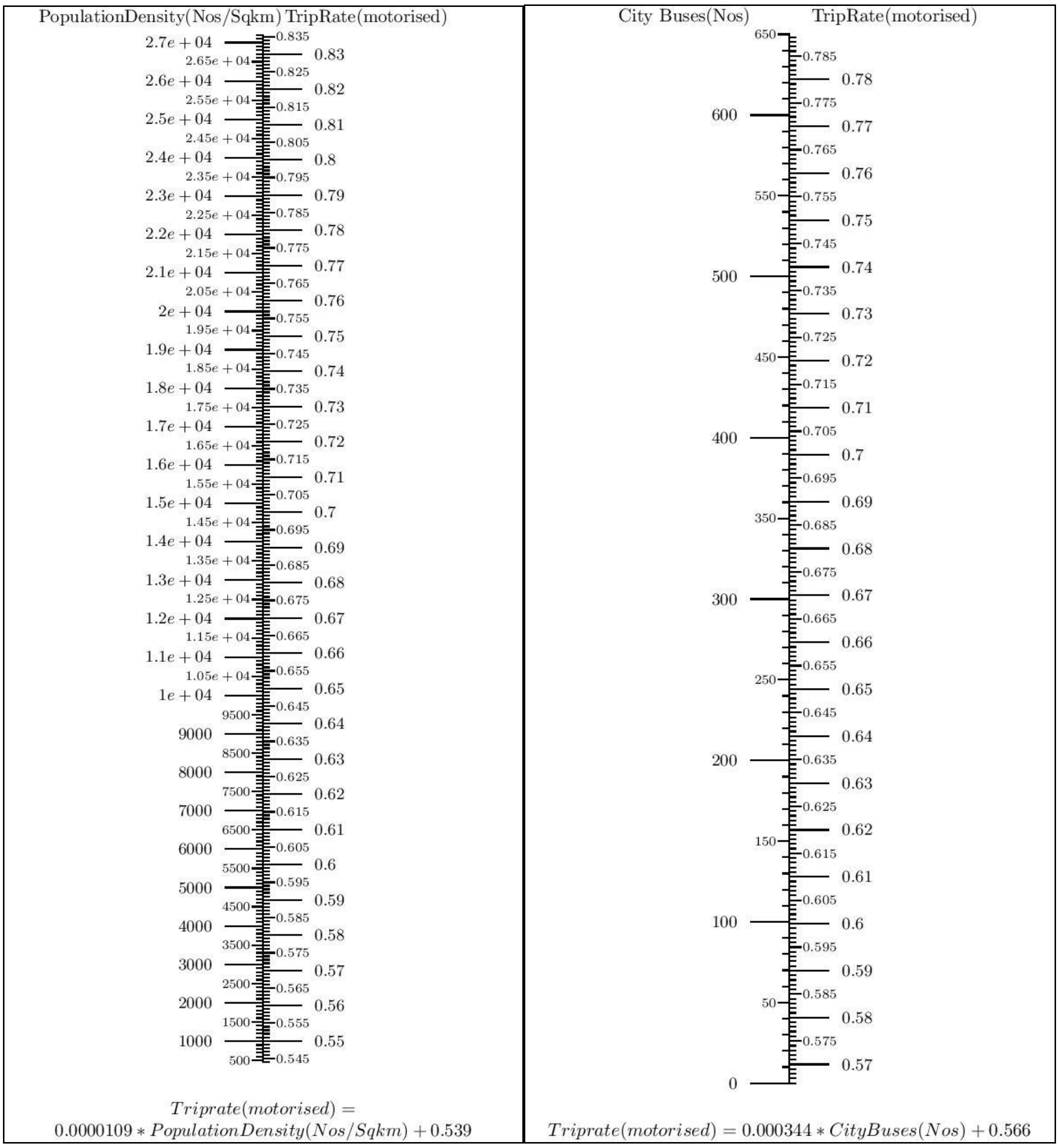
Figure 6.14: Nomogram for Motorized Trip Rate, Population and Industrial Area - CP1

Example: For Population (In Lakhs) = 1 and Industrial Area (percent) = 1, then Trip Rate (motorised) = 0.388

6.6.2. City Category -CP 2 (Population 10-40lakhs)

Single Input Variable Case:

For Medium size populated cities, Motorized Trip Rate influenced by Population Density and City buses separately. Nomograms formed with these parameters are presented in Figure 6.15.



(a) (b)

Figure 6.15: Nomograms for Motorized Trip Rate-Population Density, City Buses- CP2

Example: Population Density (Persons/sqkm) =7000, Trip Rate(motorised) = 0.616 (From Figure 6.15(a))

City Buses (In Numbers) = 500, Trip Rate(motorised) = 0.737 (From Figure 6.15(b))

Two Input Variables Case:

Population Density (Persons/sq.km) and City buses jointly used to assess the Motorized Trip Rate for cities of the population ranging from 10 to 40 Lakhs. Nomogram for this relation is formed and shown in the following Figure 6.16.

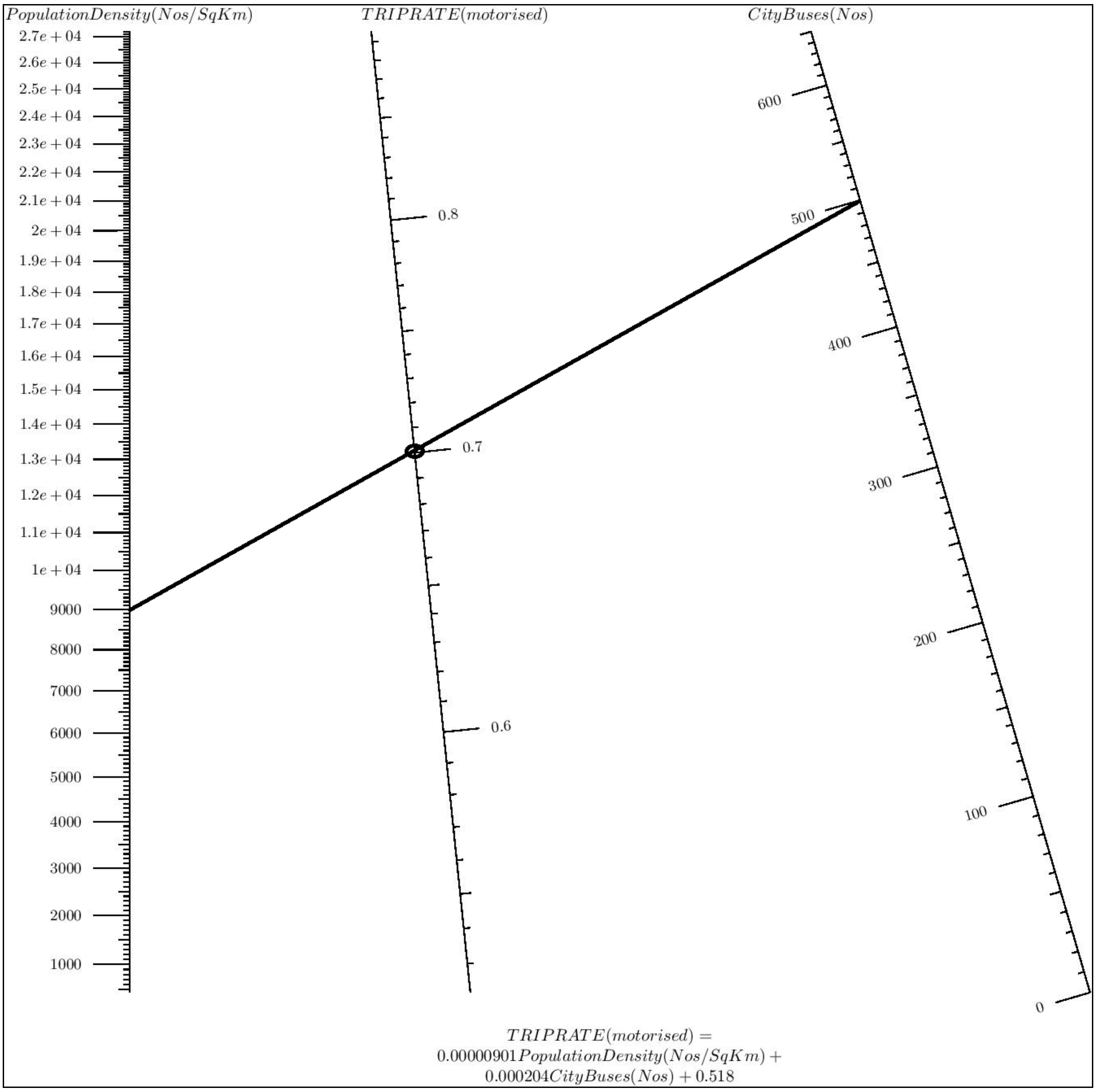


Figure 6.16: Nomogram for Motorized Trip Rate, Population Density and City buses - CP2

Example: For Population Density (Persons/Sqkm) = 9000 and City Buses (In Numbers)= 500, then Trip Rate (motorised) = 0.7

6.6.3. City Category -CP 3 (Population >40lakhs)

Single Input Variable Case:

Cities with population more than 40 Lakhs, Motorized Trip Rates are influenced by Population, City Buses, and Registered Vehicles. Based on the relation, Nomograms are made and presented in Figures 6.17 and 6.18.

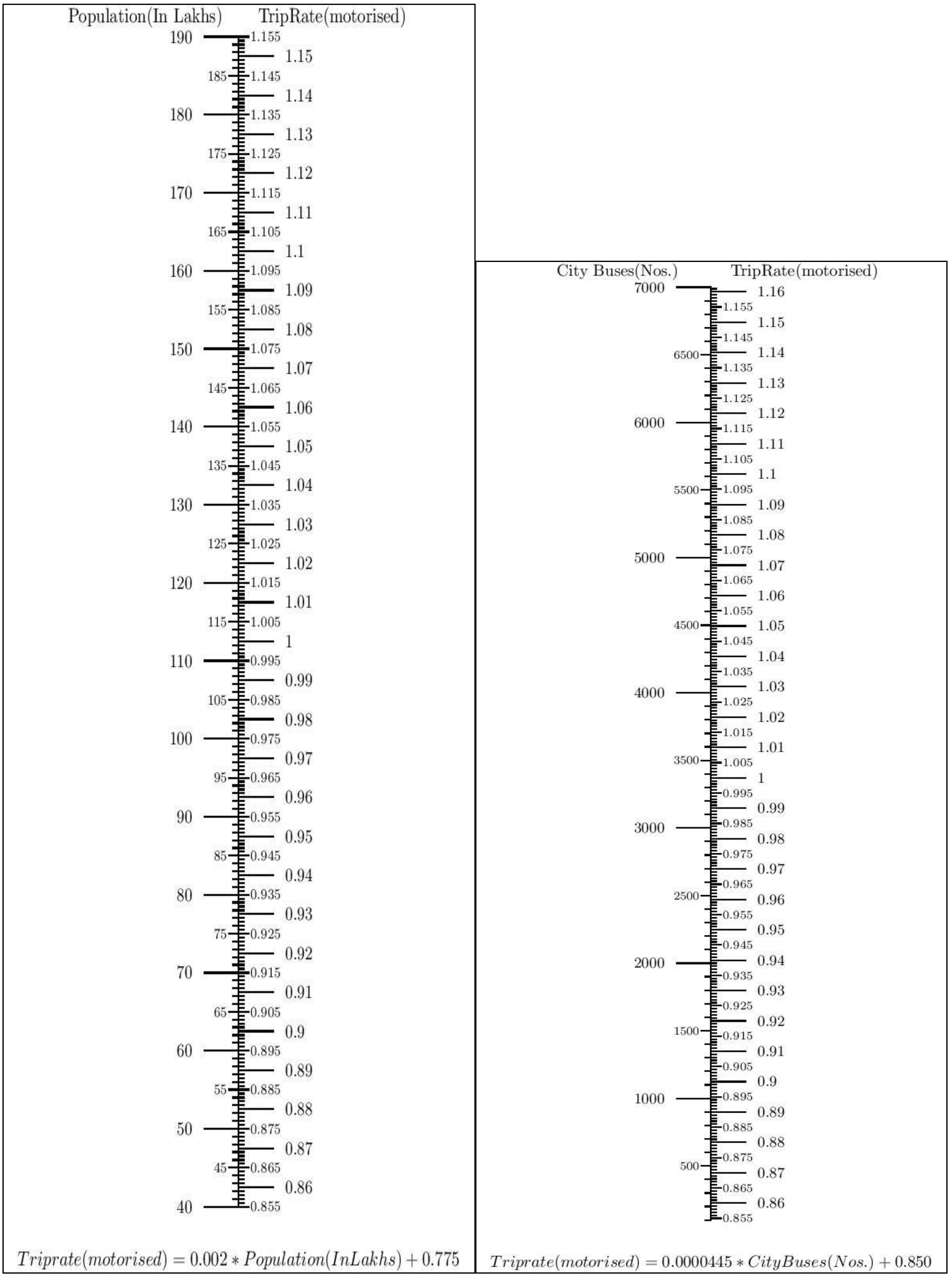


Figure 6.17: Nomograms for Motorized Trip Rate-Population and City Buses - CP3

Example: Population (In Lakhs) =100, Trip Rate(motorised) = 0.975(From Figure 6.17(a))

City Buses (In Numbers) = 3000, Trip Rate(motorised) = 0.984 (From Figure 6.17(b))

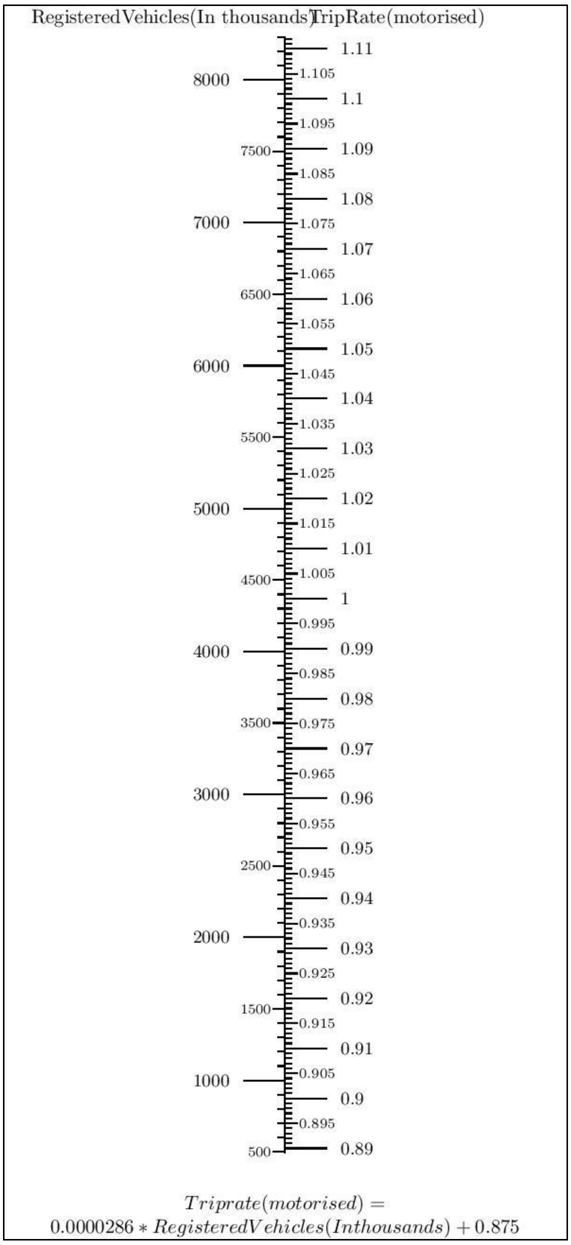


Figure 6.18: Nomograms for Motorized Trip Rate-Registered Vehicles - CP3

Example: Registered Vehicles (In thousands) =4000, Trip Rate(motorised) = 0.99(From Figure 6.18)

Two Input Variables Case:

Highly populated cities with population more than 40 Lakh, data was studied, Motorized Trip Rates are influenced by Population, City Buses and Registered Vehicles. The following are the combinations considered.

- Motorized Trip Rate Vs Population and City Buses
- Motorized Trip Rate Vs Population and Registered Vehicles

Nomograms were developed and presented in Figures 6.19 and 6.20.

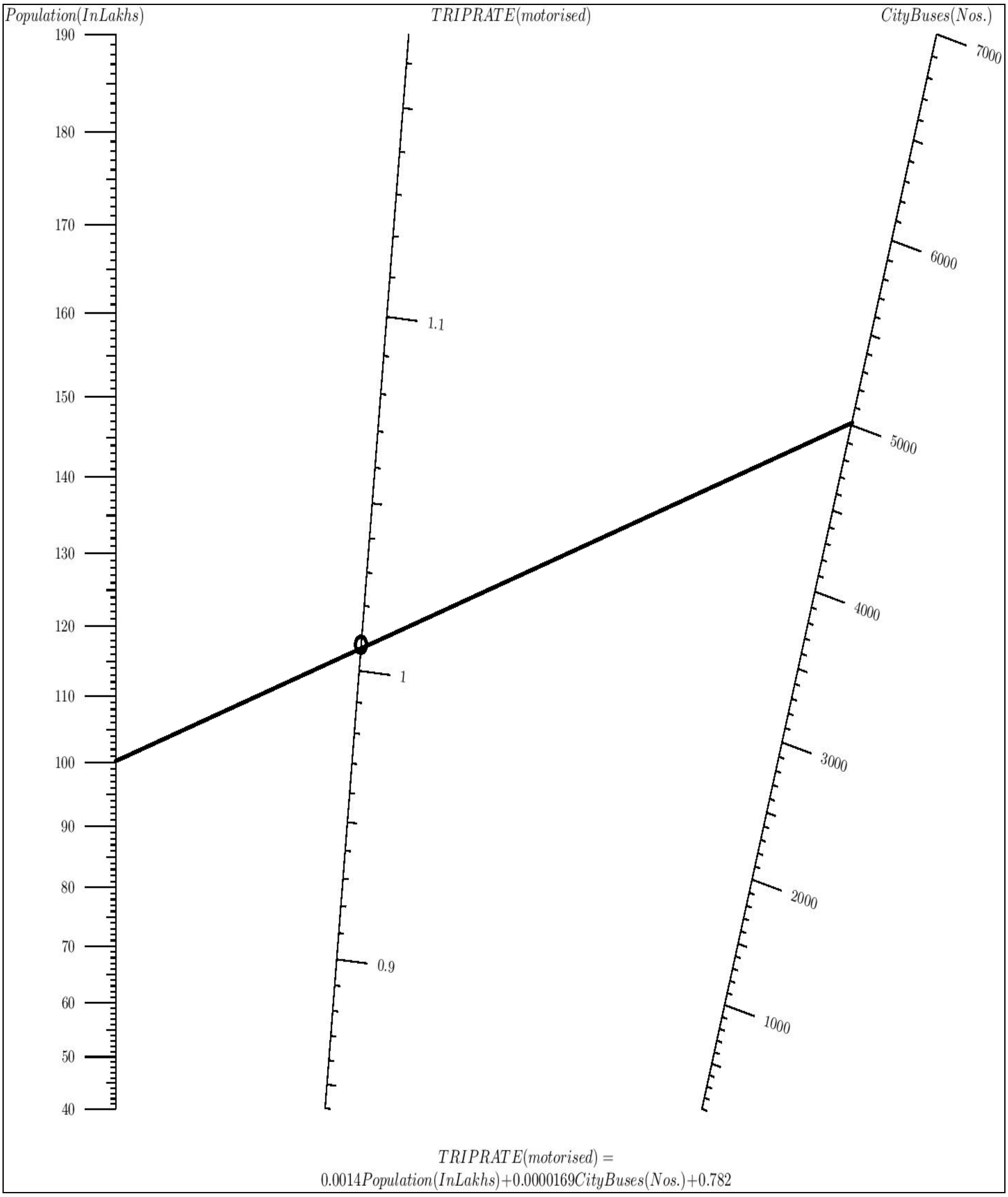


Figure 6.19: Nomogram for Motorized Trip Rate, Population and City Buses - CP3

Example: For Population (In Lakhs) = 100 and City Buses (In Numbers)= 5000, then Trip Rate (motorised) = 1.01

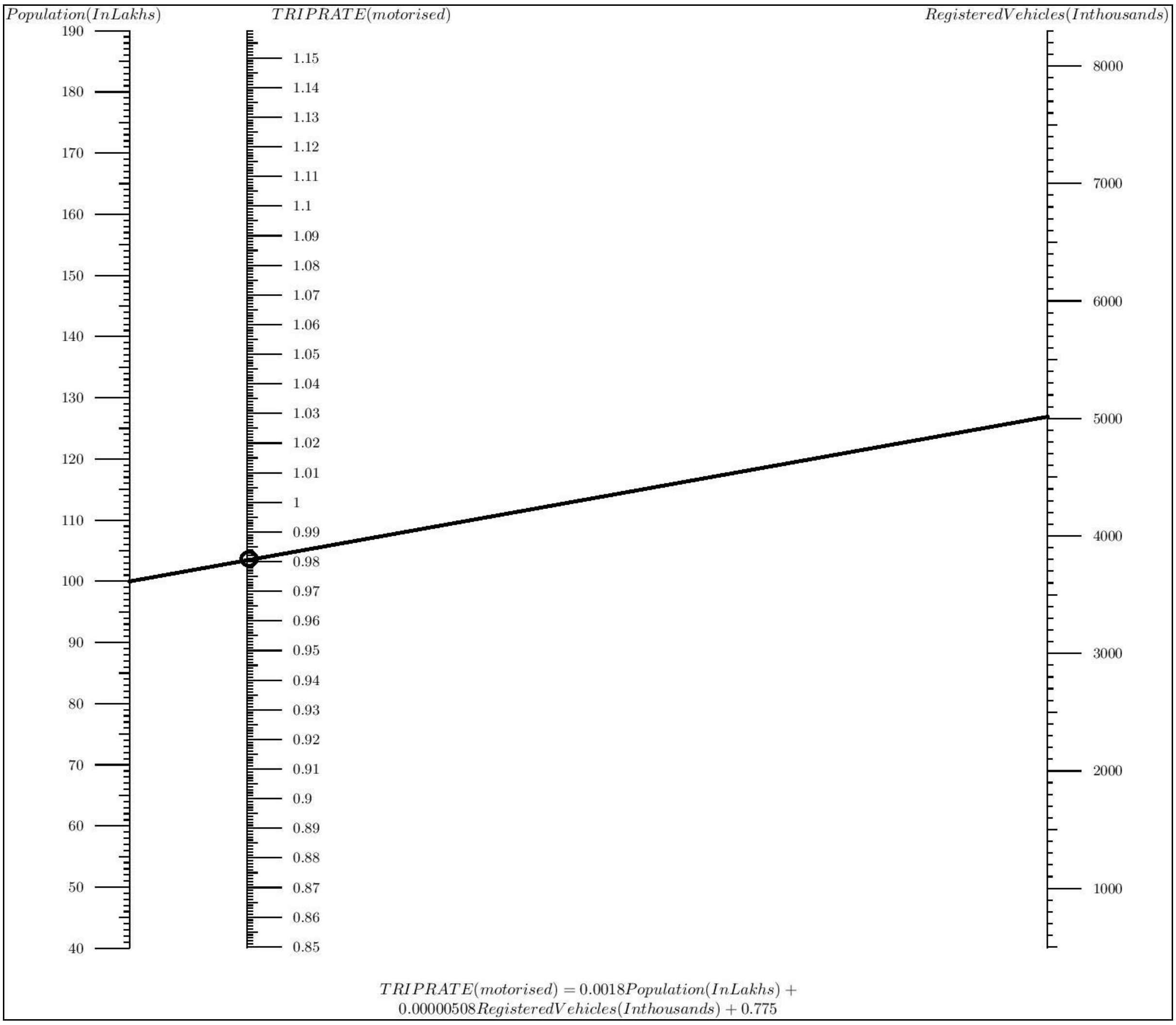


Figure 6.20: Nomogram for Motorized Trip Rate, Population and Registered Vehicles - CP3

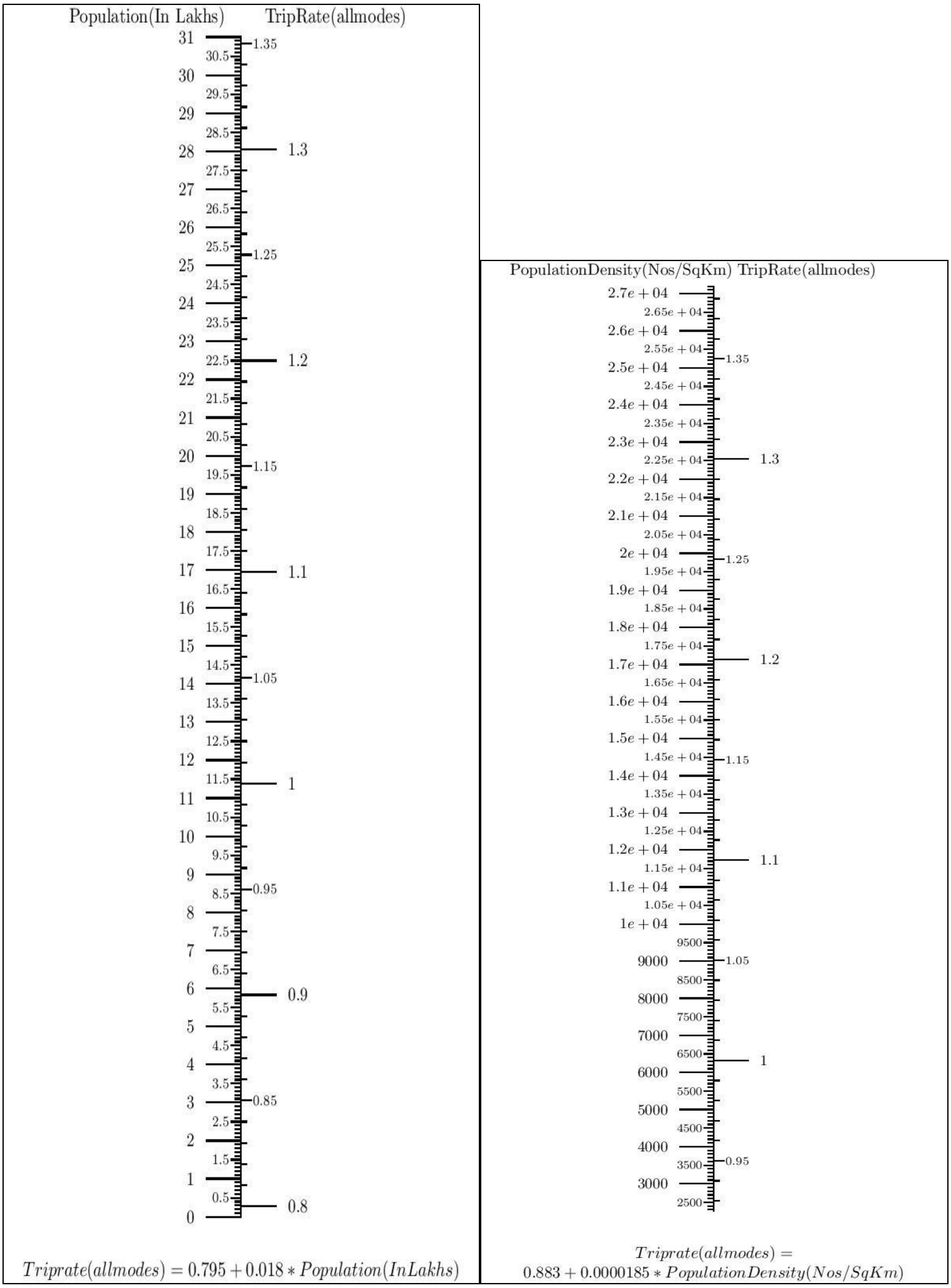
Example: For Population (In Lakhs) = 100 and Registered Vehicles (In thousands)= 5000, then Trip Rate (motorised) = 0.98

6.7. Nomograms For Trip Rate (All-Modes)-City Category Based On City Area

6.7.1. City Category -CA 1 (City Area <300 sqkm)

Single Input Variable Case:

For Cities less than 300 Sq.km geographical area, Population, Population Density, Per Capita Income and Registered Vehicles influences Trip Rate. These relations were plotted as a Nomogram and presented in following Figures 6.21 and 6.22.

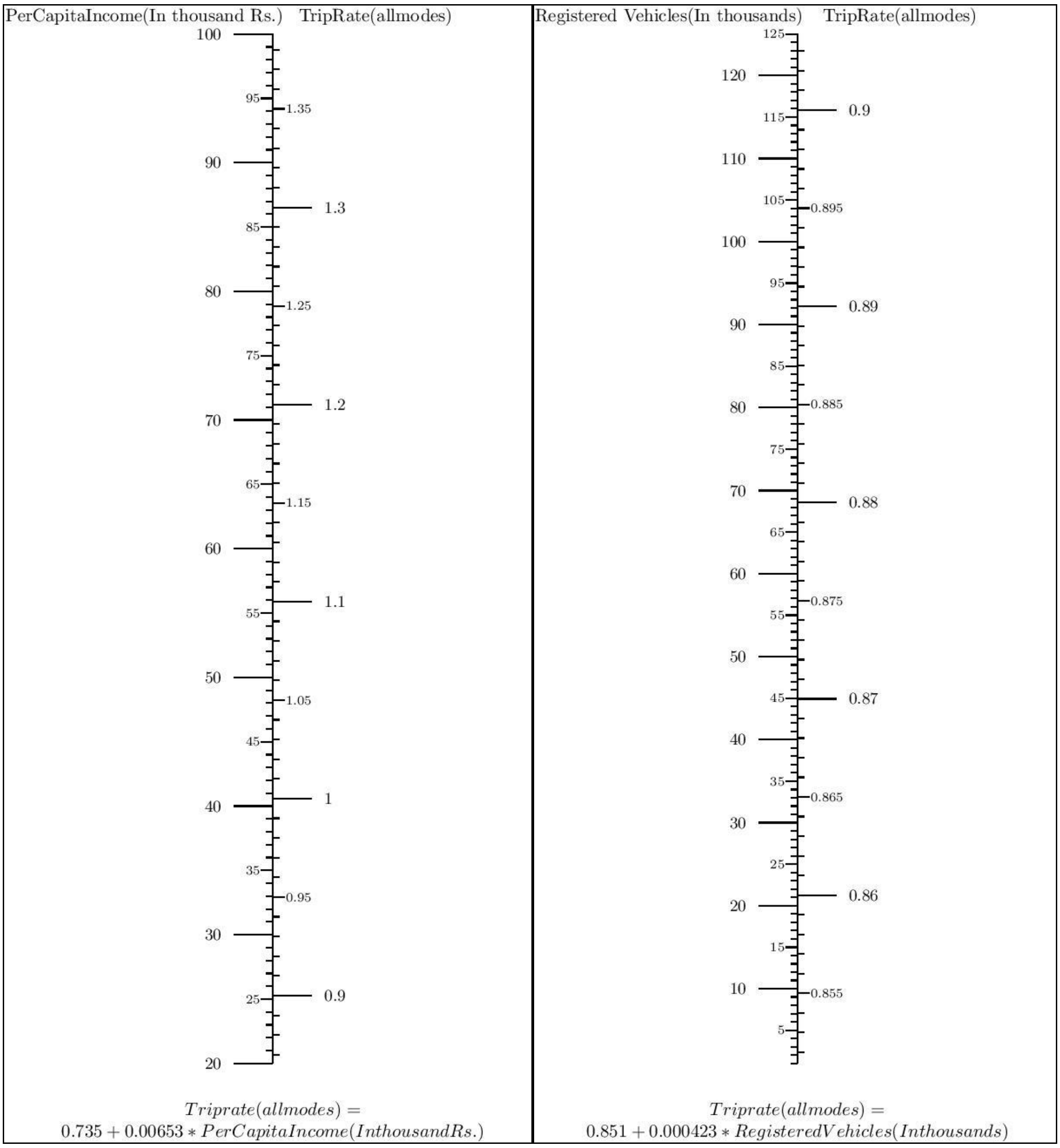


(a) (b)

Figure 6.21: Nomograms for Trip Rate-Population and Population Density - CA1

Example: Population (In Lakhs) =12, Trip Rate = 1.01(From Figure 6.21(a))

Population Density (Persons/Sqkm) = 9000, Trip Rate =1.05 (From Figure 6.21(b))



(a) (b)

Figure 6.22: Nomogram for Trip Rate-Per Capita Income and Registered Vehicles - CA1

Example: Per Capita Income (In thousands) =60, Trip Rate = 1.13 (From Figure 6.22(a))

Registered Vehicles (In thousands) = 50, Trip Rate =0.872 (From Figure 6.22(b))

Two Input Variables Case:

Small cities of this category, City Area less than 300Sq.km, Trip Rates are influenced by the Population, Per Capita Income and Registered Vehicles together with Trip Rate. The following combinations are considered.

- Trip Rate Vs Population and Registered Vehicles
- Trip Rate Vs Per Capita Income and Registered Vehicles

These are given as a Nomogram in Figures 6.23 and 6.24, respectively.

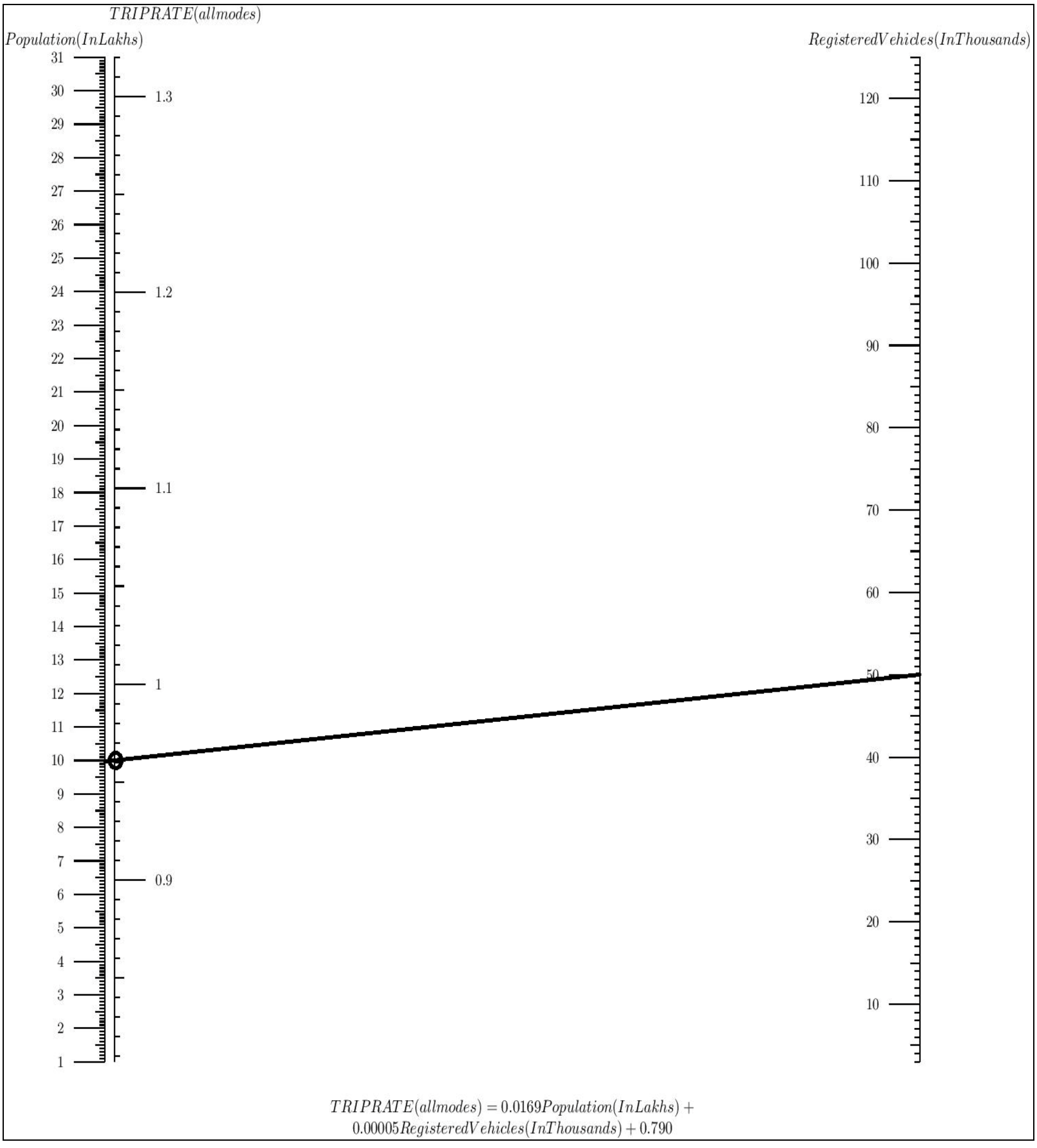


Figure 6.23: Nomogram for Trip Rate, Population and Registered Vehicles - CA1

Example: For Population (In Lakhs) = 10 and Registered Vehicles (In thousands)= 50, then Trip Rate = 0.96

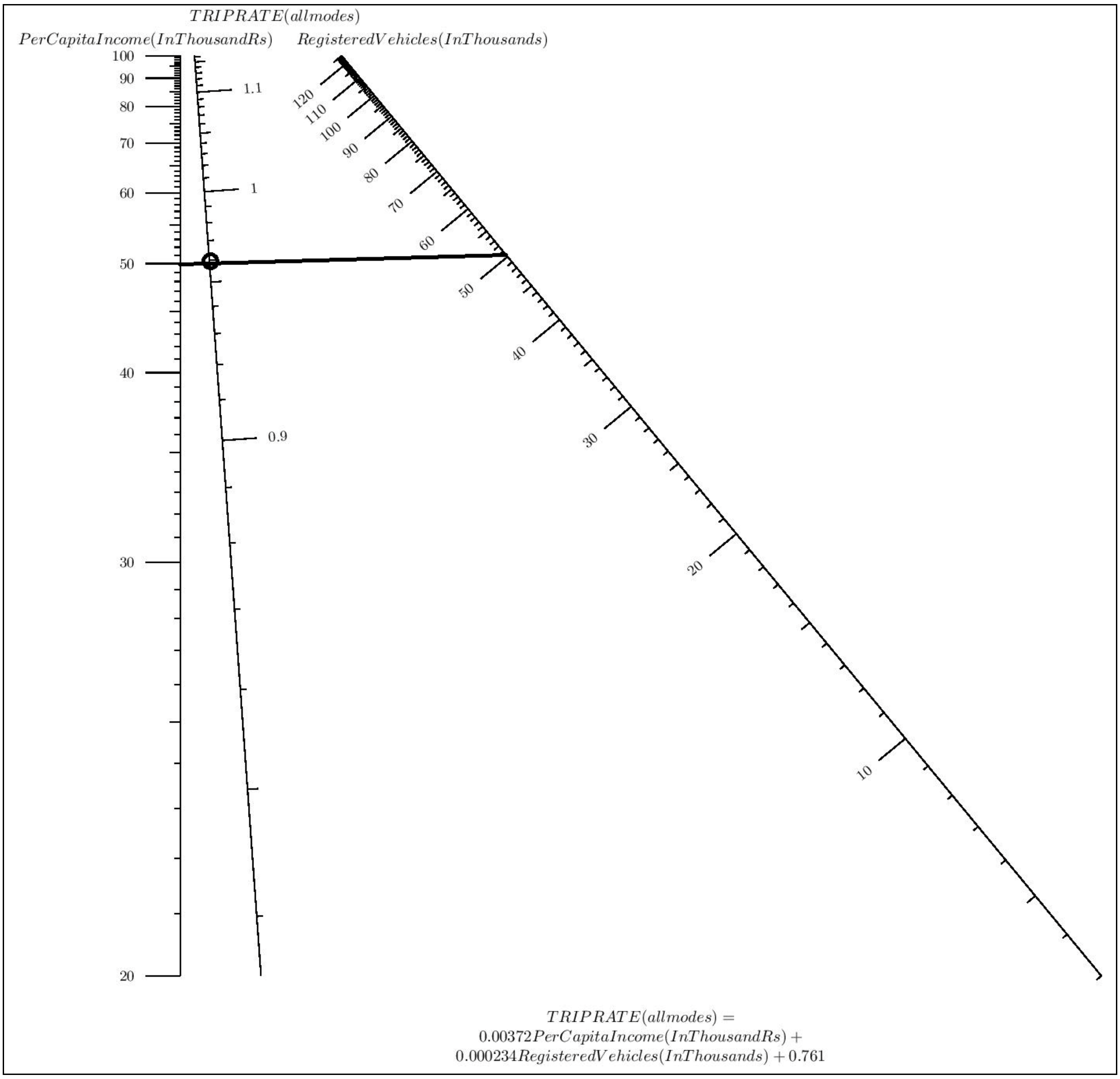


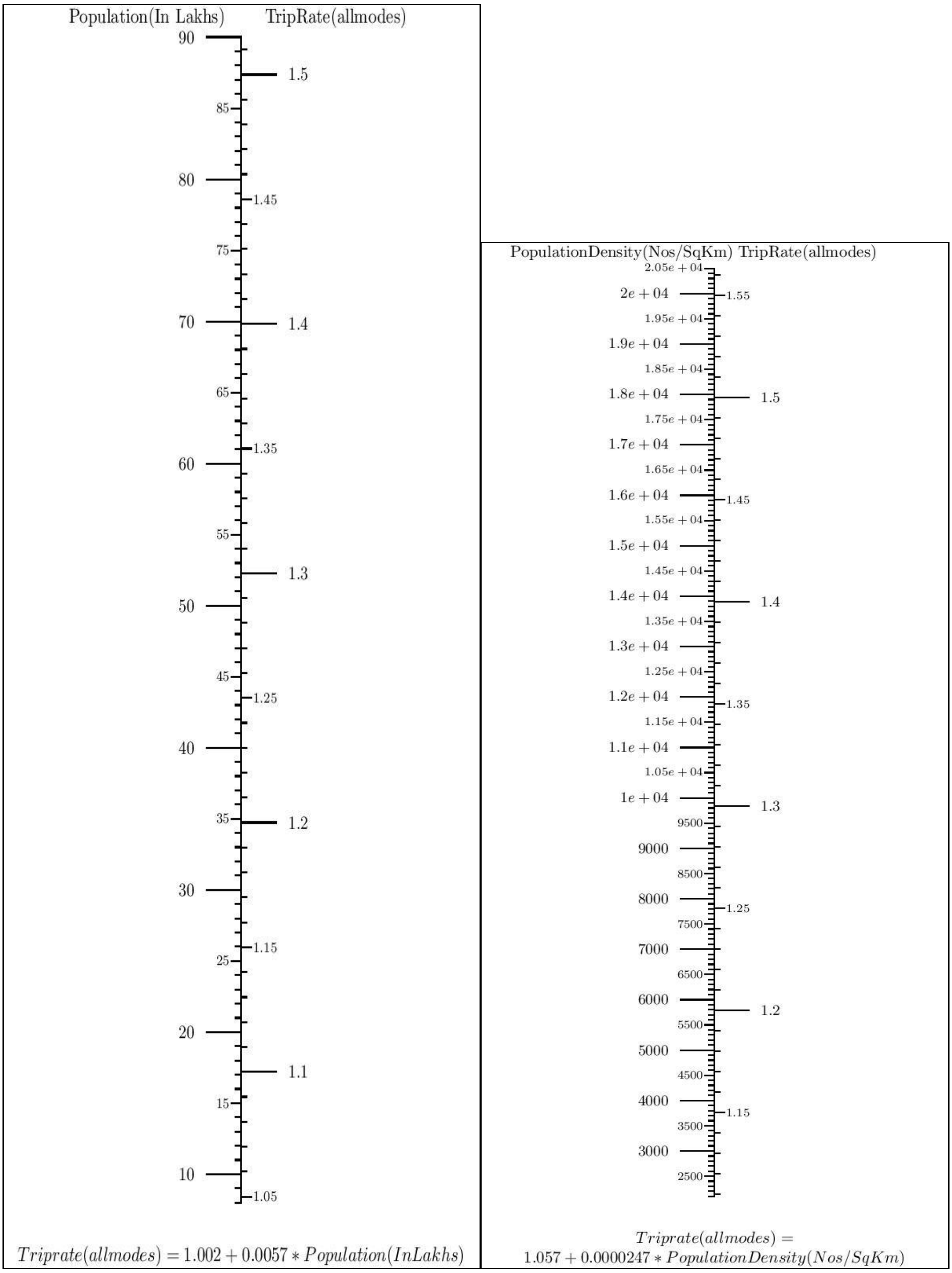
Figure 6.24: Nomogram for Trip Rate, Per Capita Income and Registered Vehicles - CA1

Example: For Per Capita Income (In thousands) = 50 and Registered Vehicles (In thousands)= 50, then Trip Rate = 0.96

6.7.2. City Category -CA 2 (City Area 300-1000 sqkm)

Single Input Variable Case:

Cities with area range between 300 to 1000 sq.km, Trip Rate influences Population, Population Density, Registered Vehicles, and City buses separately. Corresponding Nomograms are presented in following Figures 6.25 and 6.26.

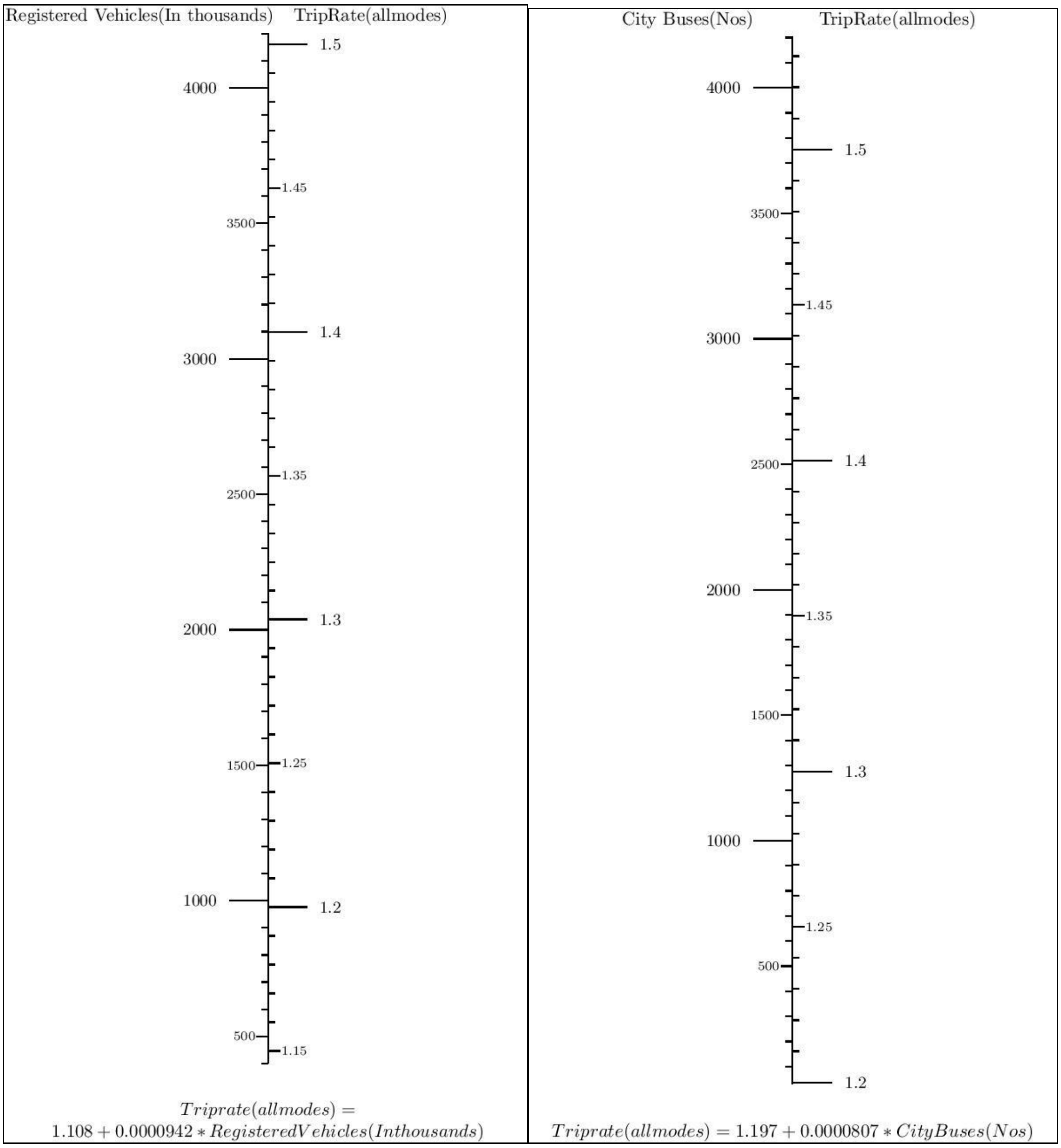


(a) (b)

Figure 6.25 : Nomograms for Trip Rate-Population and Population Density- CA2

Example: Population (In Lakhs) =70, Trip Rate = 1.4(From Figure 6.25(a))

Population Density (Persons/Sqkm) = 9000, Trip Rate =1.27 (From Figure 6.25(b))



(a) (b)

Figure 6.26: Nomograms for Trip Rate-Registered Vehicles and City Buses - CA2

Example: Registered Vehicles (In thousands) =3000, Trip Rate = 1.39(From Figure 6.26(a))

City Buses (In Numbers) = 3000, Trip Rate =1.44 (From Figure 6.26(b))

Two Input Variables Case:

Trip Rate of these medium sized cities influenced by Population, Population Density, City Buses and Registered Vehicles together with Trip Rate. The following are the combinations considered.

- Trip Rate Vs Population and Population Density
- Trip Rate Vs Population Density and City Buses

- Trip Rate Vs Population Density and Registered Vehicles

The Nomograms were developed for above combinations and presented in Figures 6.27 to 6.29.

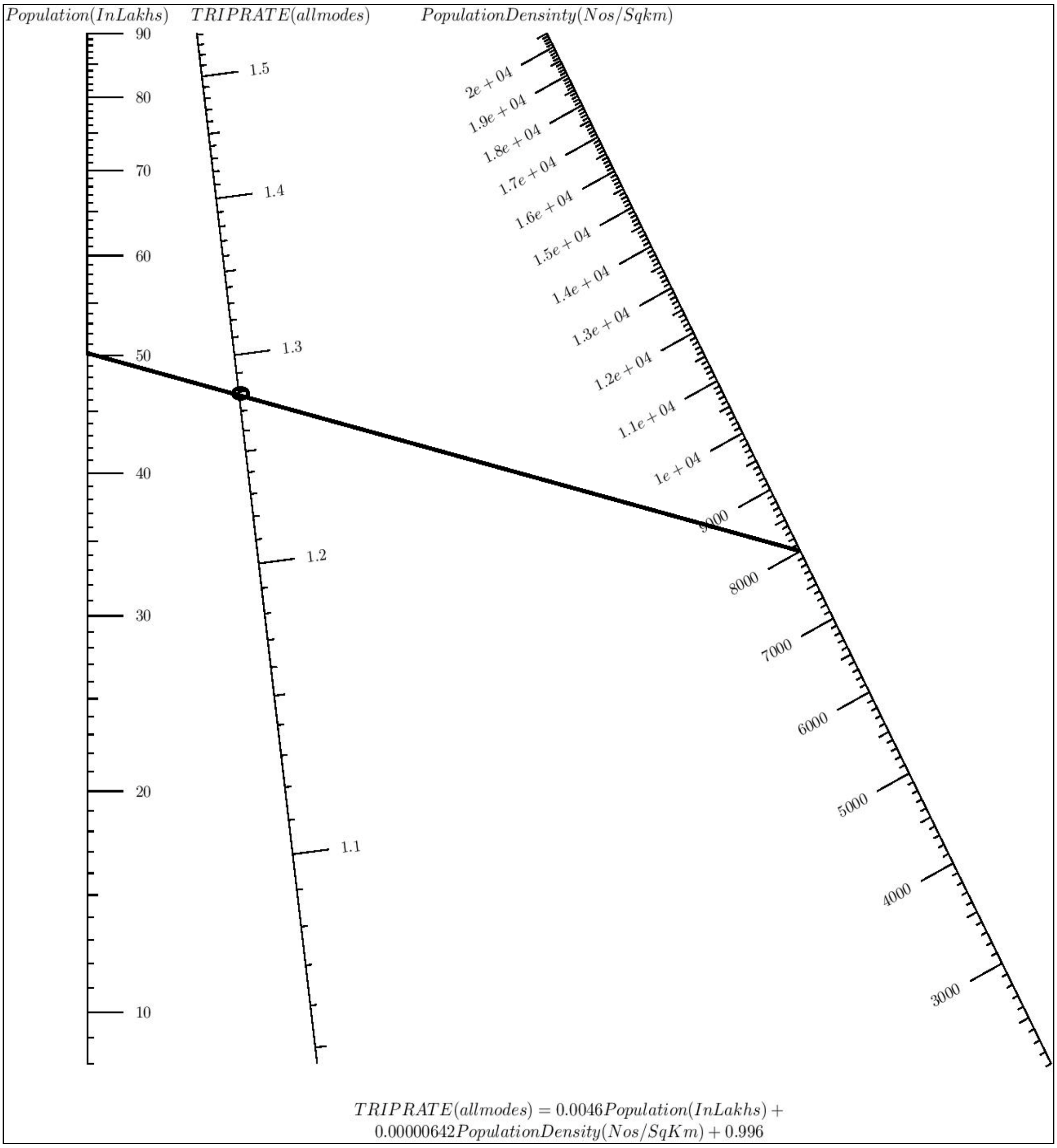


Figure 6.27: Nomogram for Trip Rate, Population and Population Density - CA2

Example: For Population (In Lakhs) = 50 and Population Density (Persons/SqKm)= 8000, then Trip Rate = 1.28

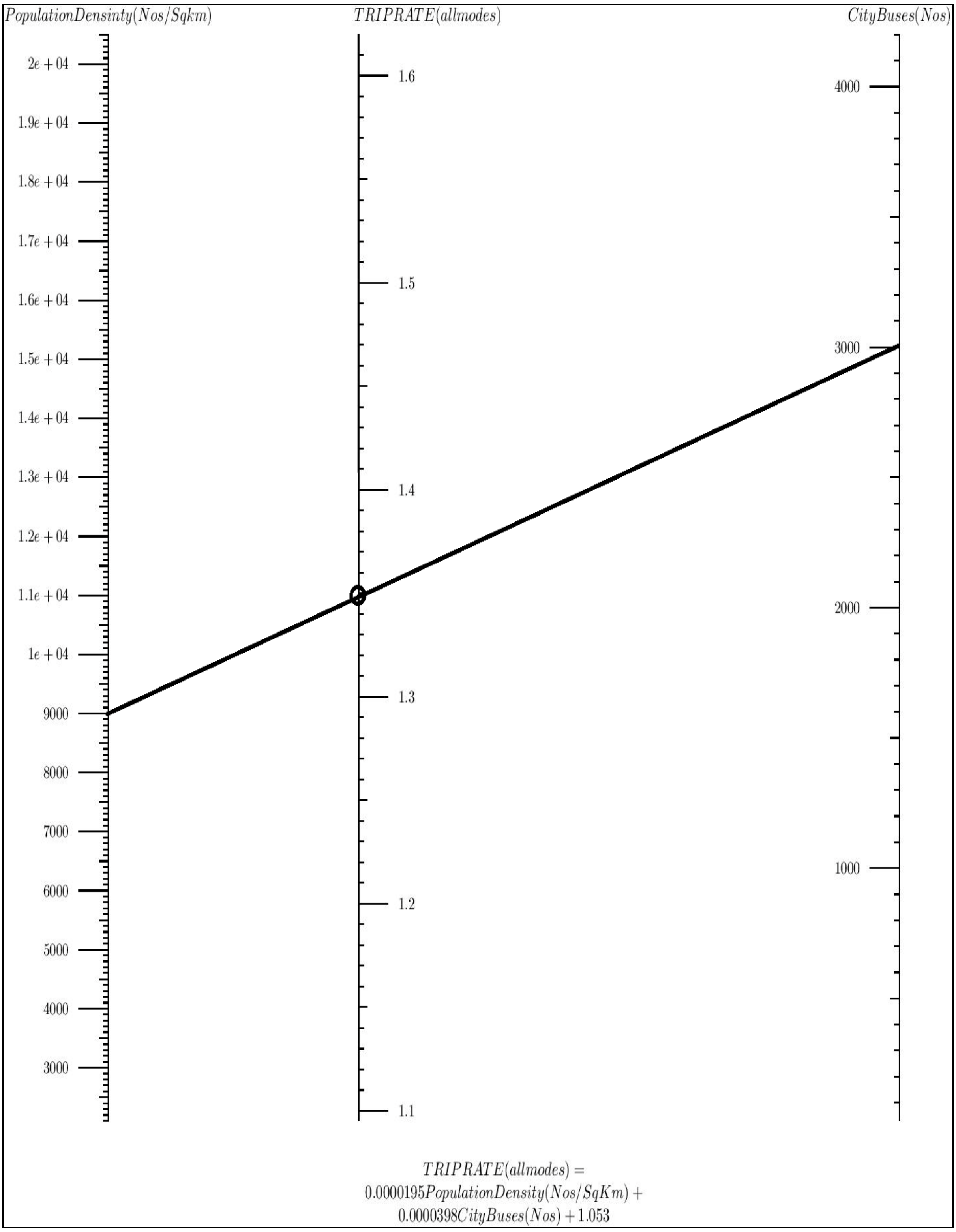


Figure 6.28: Nomogram for Trip Rate, Population Density and City Buses - CA2

Example: For Population Density (Persons/SqKm)= 9000 and City Buses(In Numbers) = 3000, then Trip Rate = 1.35

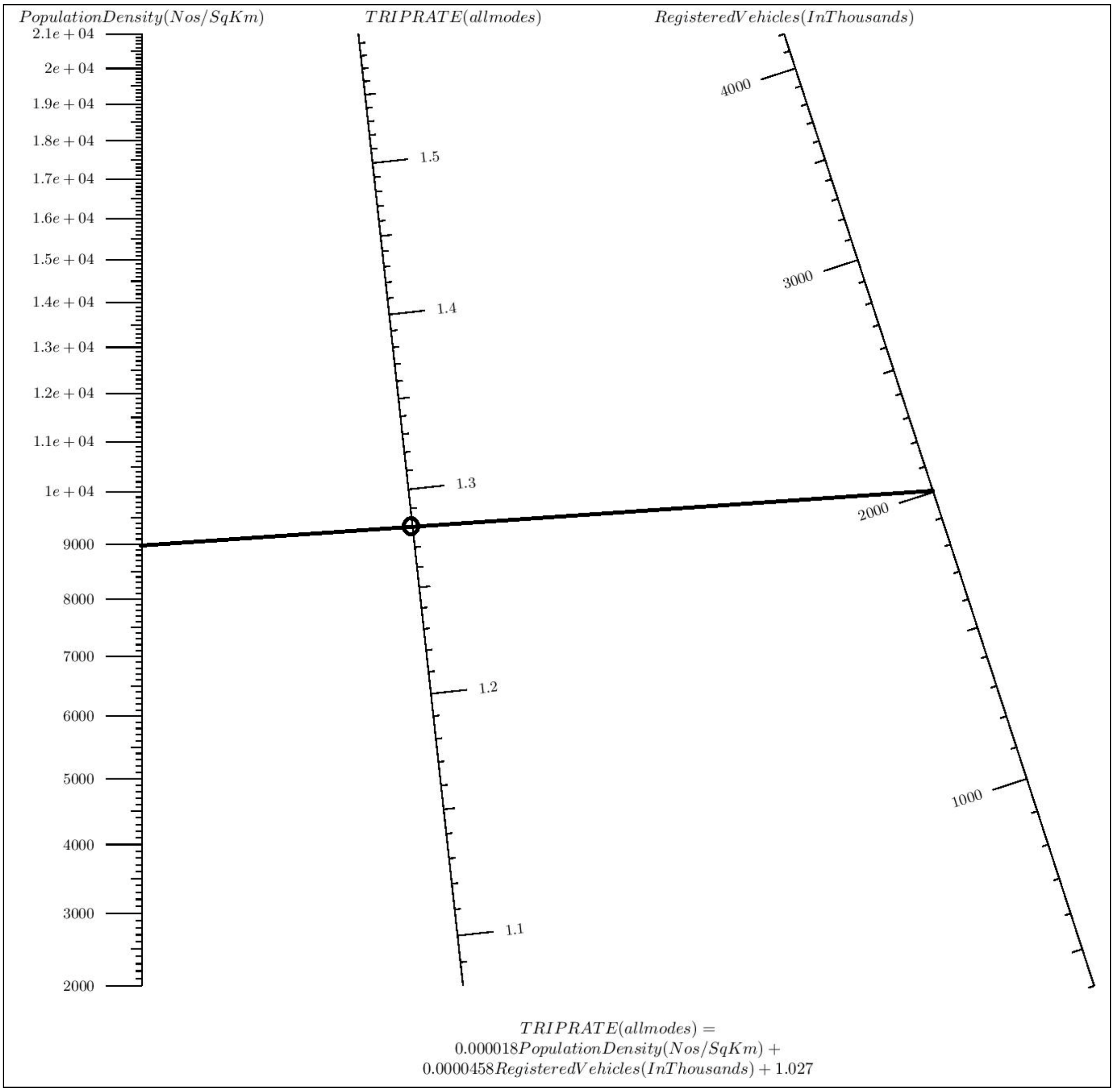


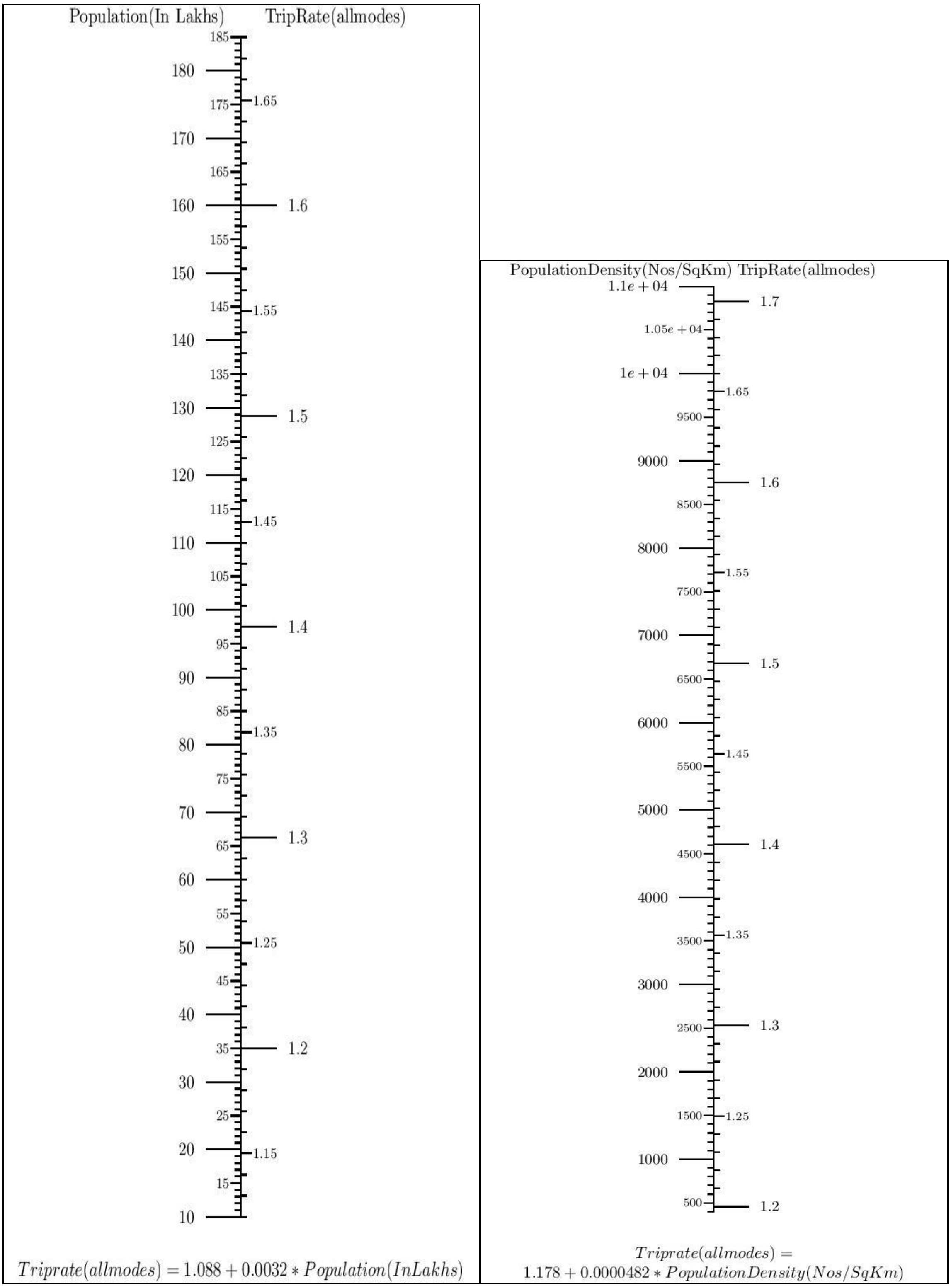
Figure 6.29: Nomogram for Trip Rate, Population Density and Registered Vehicles - CA2

Example: For Population Density (Persons/SqKm)= 9000 and Registered Vehicles (In thousands) = 2000, then Trip Rate = 1.28

6.7.3. City Category -CA 3 (City Area >1000 sqkm)

Single Input Variable Case:

Variables like Population, Population Density, City Buses and Registered Vehicles influences Trip Rate for cities of the area more than 1000 sq.km. Nomograms are presented based on these in Figures 6.30 and 6.31.

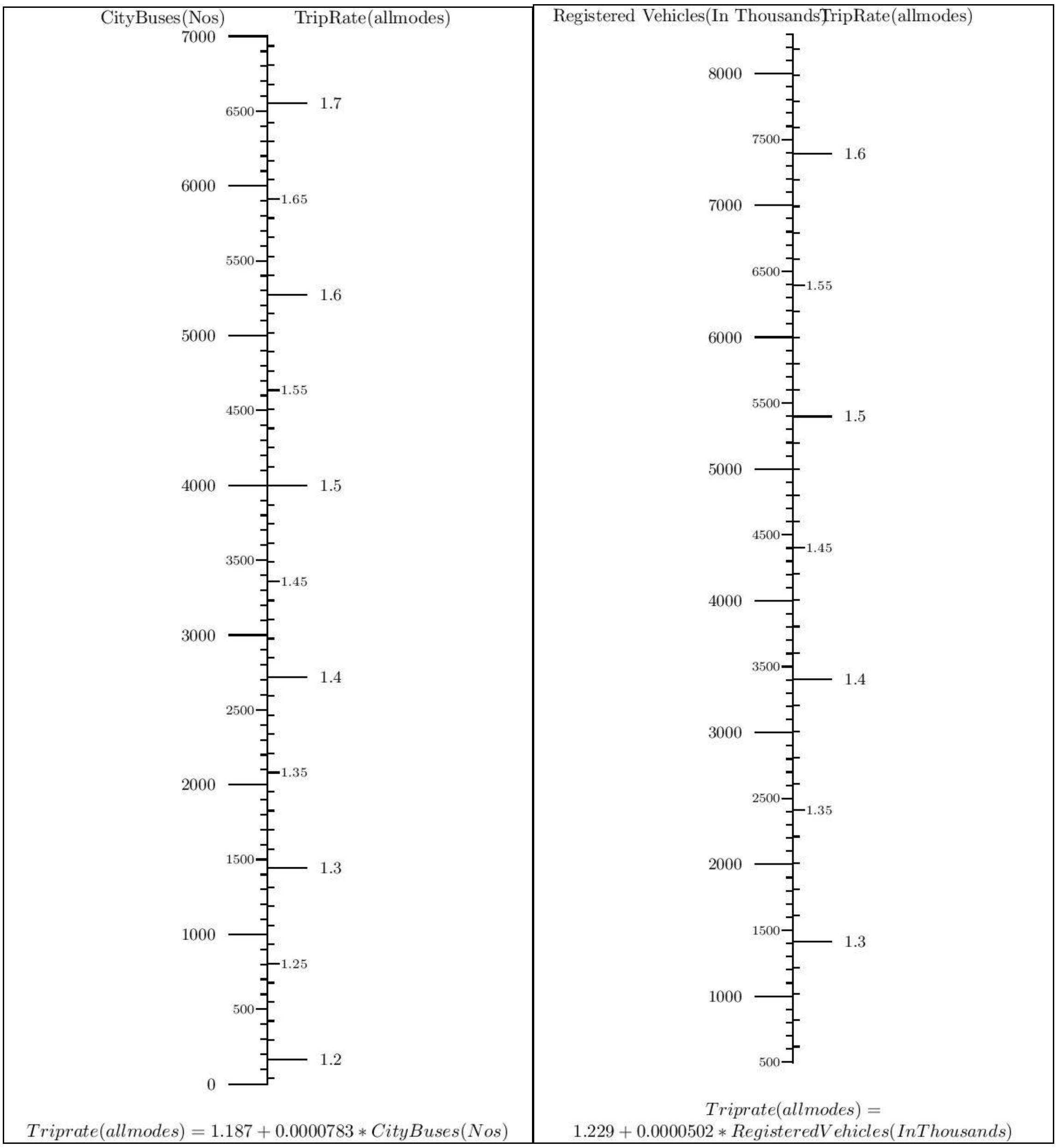


(a) (b)

Figure 6.30: Nomograms for Trip Rate – Population and Population Density - CA3

Example: Population (In Lakhs) =70, Trip Rate = 1.31(From Figure 6.30(a))

Population Density (Persons/Sqkm) = 9000, Trip Rate =1.61 (From Figure 6.30(b))



(a) (b)

Figure 6.31: Nomogram for Trip Rate-City Buses and Registered Vehicles - CA3

Example: City Buses (In Numbers) =5000, Trip Rate = 1.58(From Figure 6.31(a))

Registered Vehicles (In thousands) = 5000, Trip Rate =1.47 (From Figure 6.31(b))

Two Input Variables Case:

The following are the various variable combinations used in the preparation of Nomogram for big cities of the area more than 1000 sq.km.

- Trip Rate Vs City Buses and Registered Vehicles
- Trip Rate Vs Population Density and Registered Vehicles

Nomograms prepared for these combinations are presented in following Figures 6.32 and 6.33.

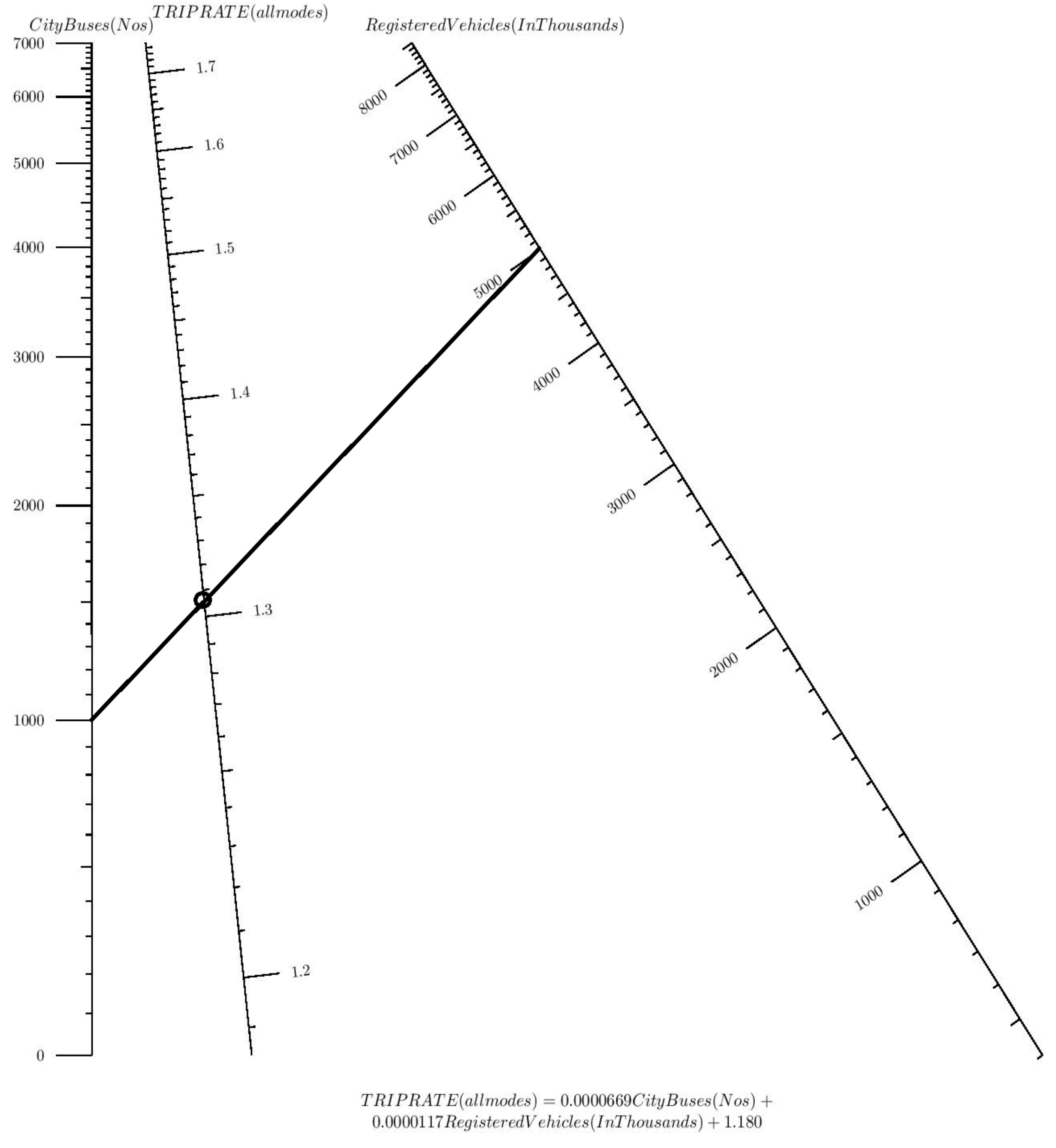


Figure 6.32: Nomogram for Trip Rate, City Buses and Registered Vehicles - CA3

Example: For City Buses (In thousands) = 1000 and Registered Vehicles (In thousands)= 5000, then Trip Rate = 1.31 (From Figure 6.32)

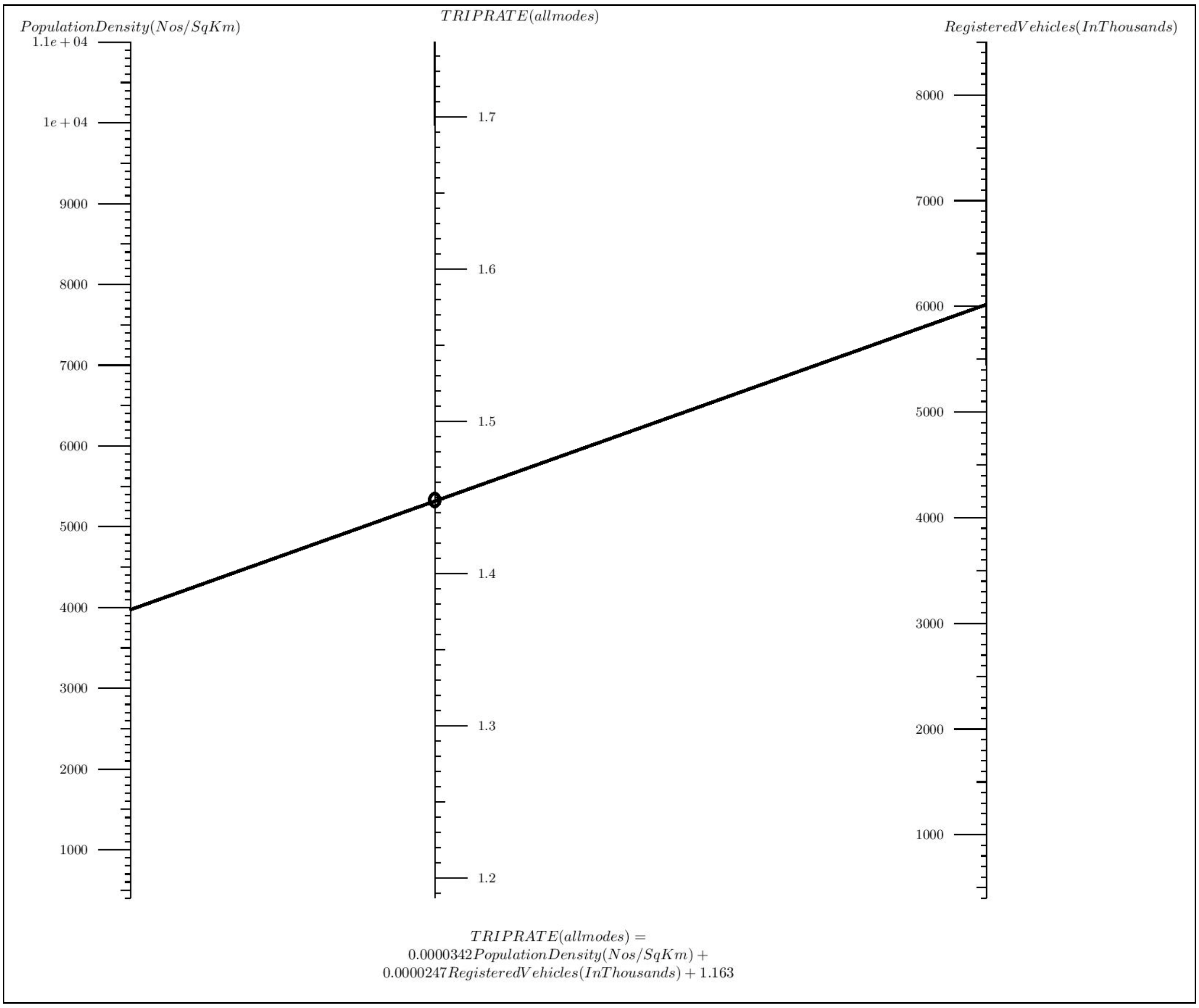


Figure 6.33: Nomogram for Trip Rate, Population Density and Registered Vehicles - CA3

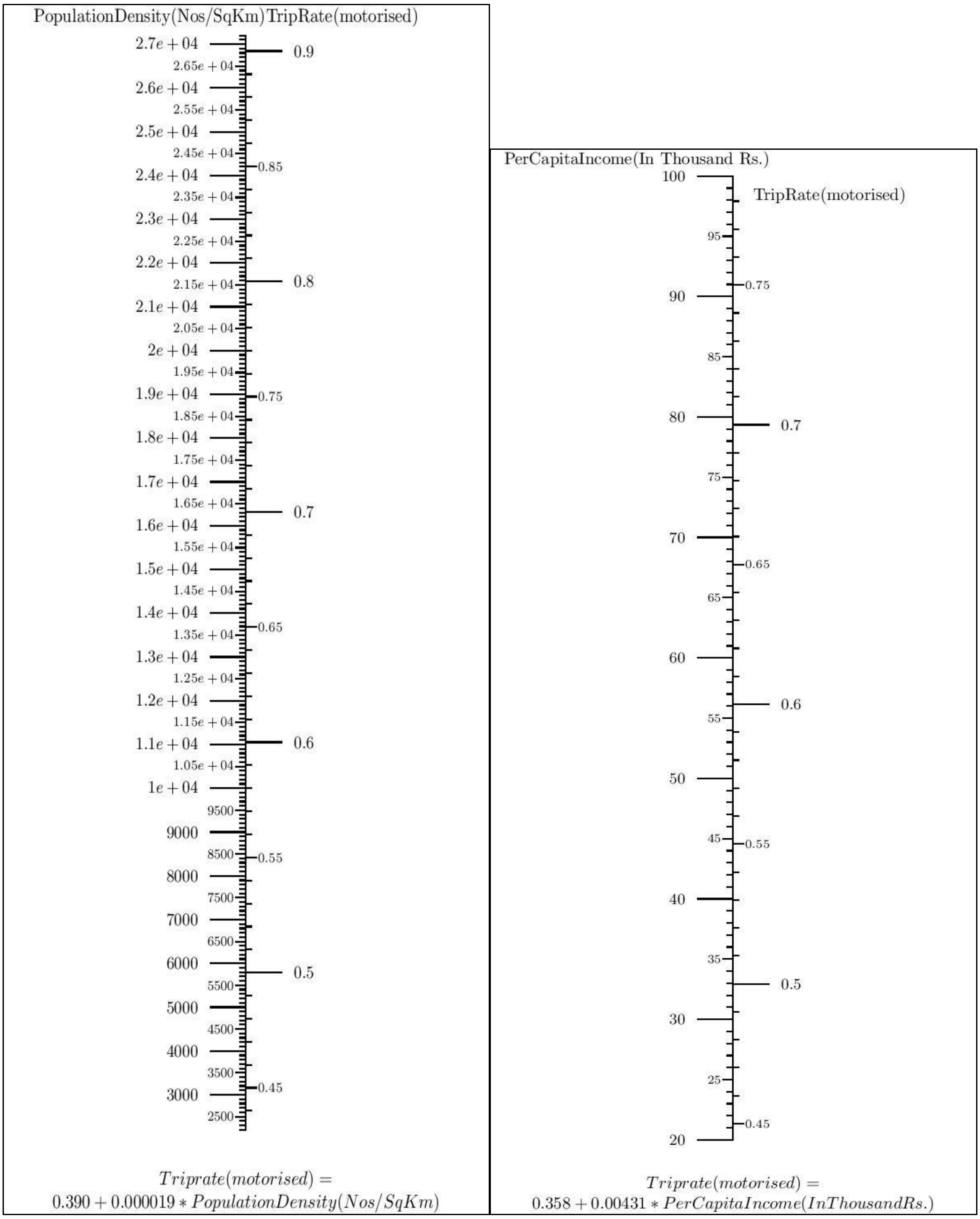
Example: For Population Density (Persons/sqkm) = 4000 and Registered Vehicles (In thousands)= 6000, then Trip Rate = 1.45 (From Figure 6.33)

6.8. Nomograms for Motorized Trip Rate - City Category Based on City Area

6.8.1. City Category -CA 1 (City Area <300 sqkm)

Single Input Variable Case:

Variables like Population Density, Per Capita Income and City buses influences Motorized Trip Rate for cities of an area less than 300Sq.km. Nomograms are presented in the following Figures 6.34 and 6.35.



(a) (b)

Figure 6.34: Nomograms for Motorized Trip Rate- Population Density and Per Capita Income - CA1

Example: Population Density (Persons/Sqkm) =9000, Trip Rate (motorised) = 0.56(From Figure 6.34(a))

Per Capita Income (In thousands) = 70, Trip Rate (motorised) =0.66 (From Figure 6.34(b))

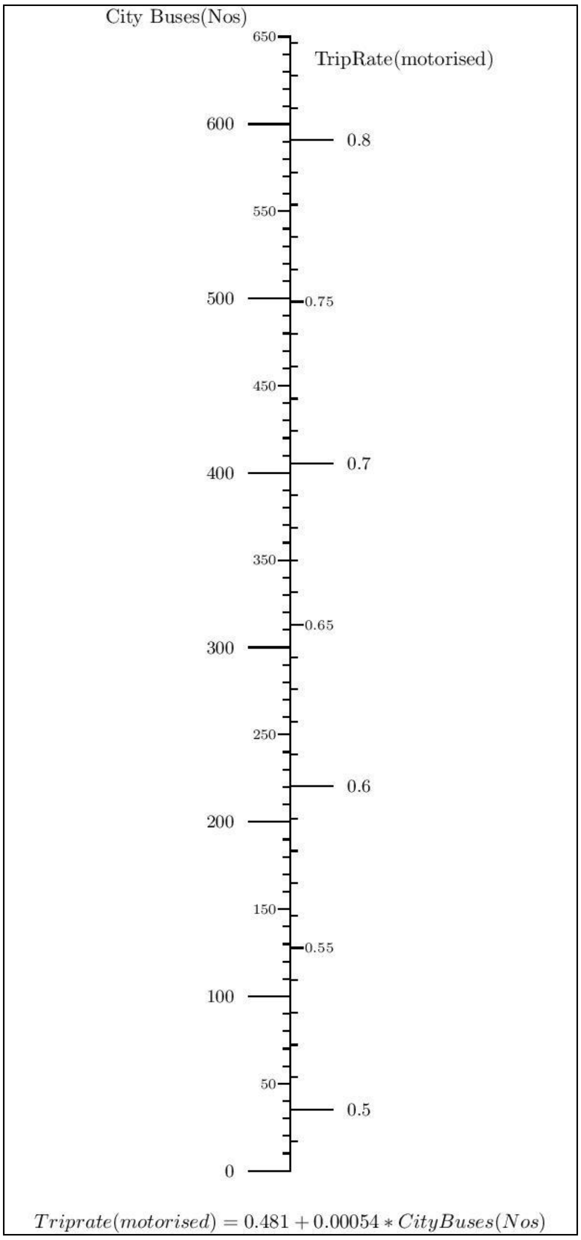


Figure 6.35: Nomograms for Motorized Trip Rate- City Buses - CA1

Example: City Buses (In Numbers) =400, Trip Rate (motorised) = 0.7

Two Input Variables Case:

The following are the various variable combinations used in the preparation of Nomogram for small cities of an area less than 300Sq.km.

- Motorized Trip Rate Vs Population Density and City Buses

Nomograms prepared for these combinations are presented in Figure 6.36.

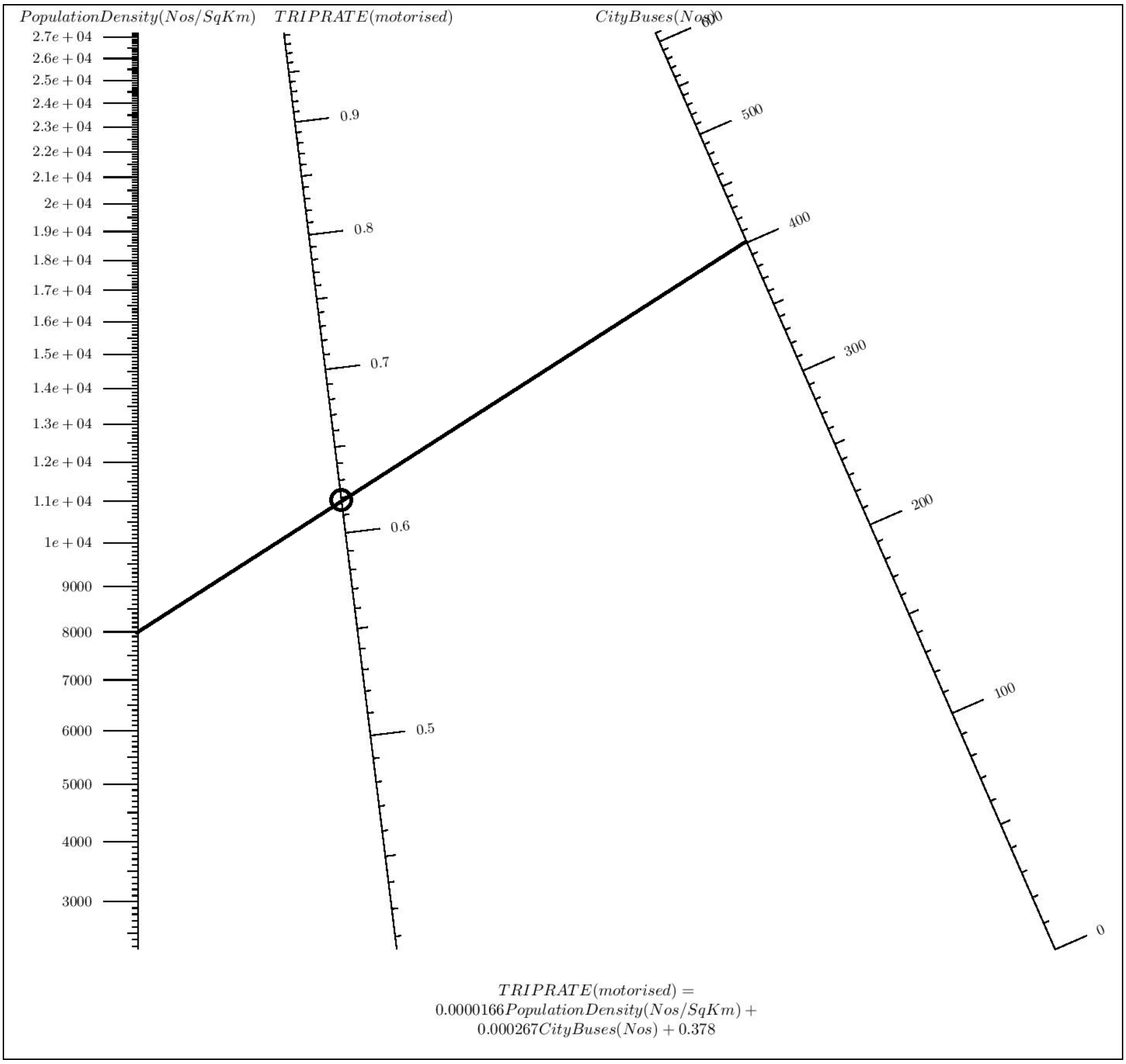


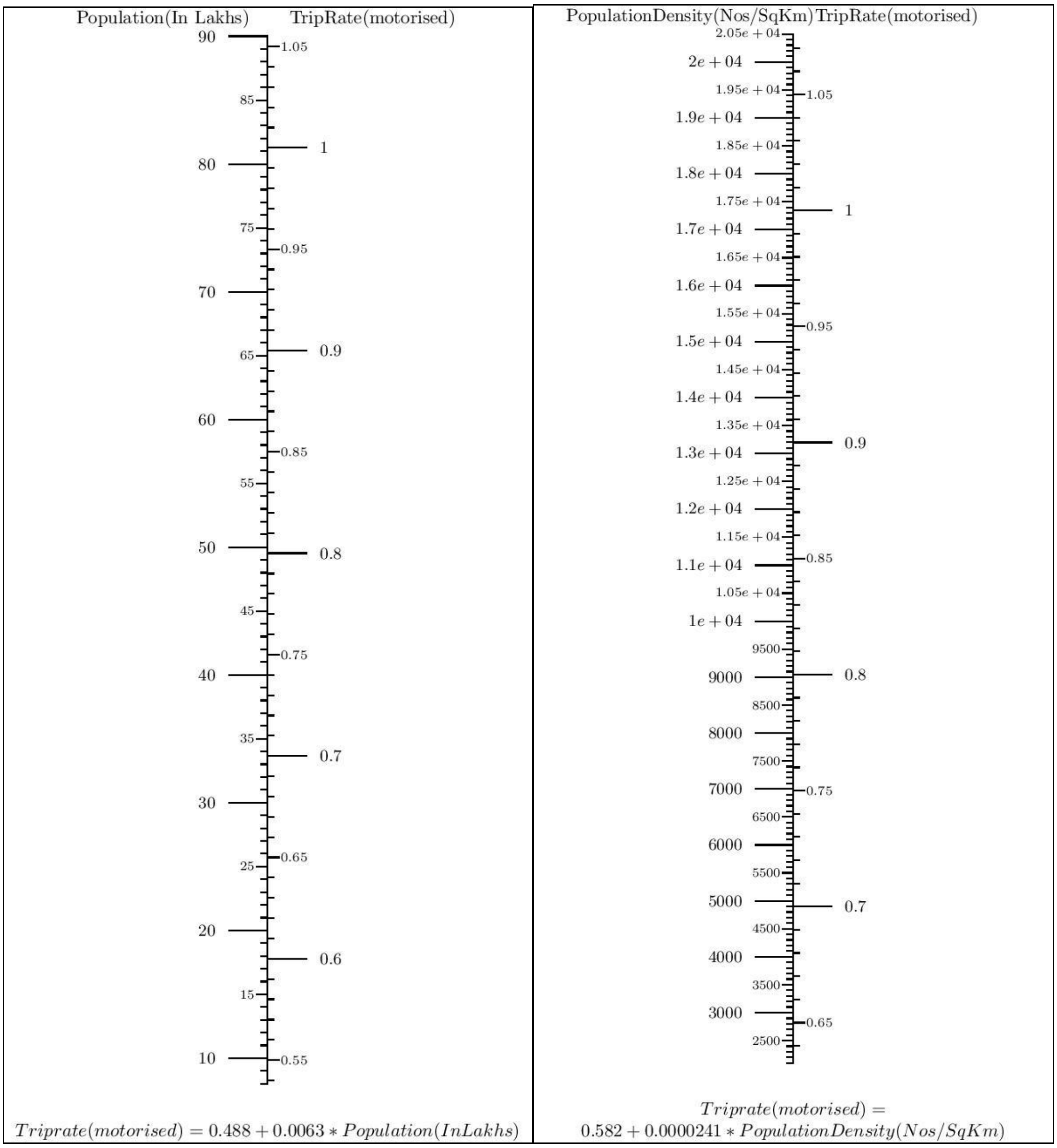
Figure 6.36: Nomogram for Motorized Trip Rate, Population Density and City Buses - CA1

Example: For Population Density (Persons/sqkm) = 8000 and City Buses (In Numbers)= 400, then Trip Rate (motorised) = 0.62

6.8.2. City Category -CA 2 (City Area 300-1000 sqkm)

Single Input Variable Case

Variables like Population, Population Density, City Buses and Registered Vehicles influences Motorized Trip Rate for cities of the area between 300 to 1000 sq.km. Developed nomograms are presented in Figures 6.37 and 6.38.

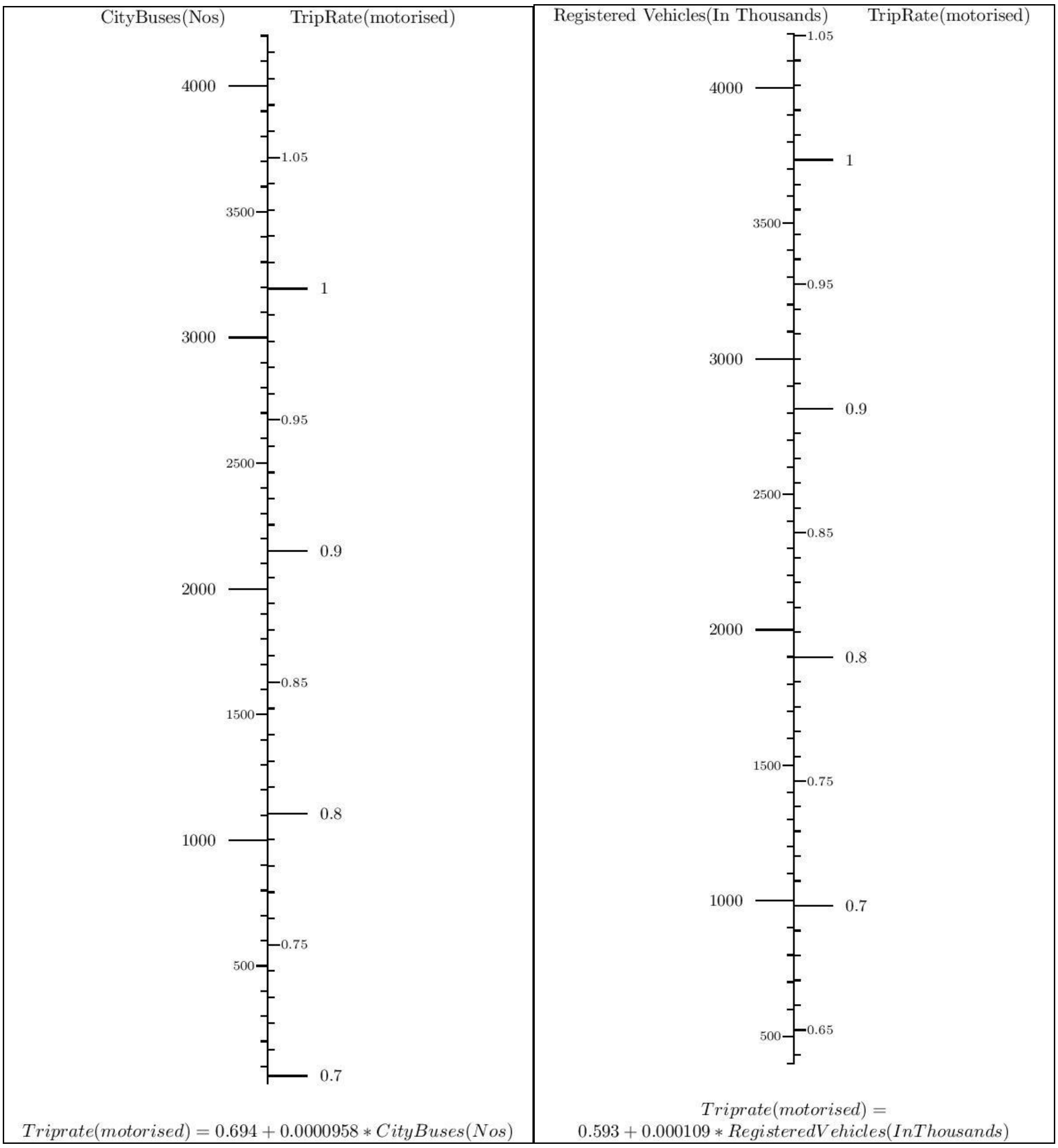


(a) (b)

Figure 6.37: Nomograms for Motorized Trip Rate –Population and Population Density - CA2

Example: Population (In Lakhs) =50, Trip Rate (motorised) = 0.8(From Figure 6.37(a))

Population Density (Persons/Sqkm) = 9000, Trip Rate (motorised) =0.8 (From Figure 6.37(b))



(a) (b)

Figure 6.38 : Nomograms for Motorized Trip Rate -City Buses and Registered Vehicles - CA2

Example: City Buses (In Numbers) =1000, Trip Rate (motorised) = 0.79(From Figure 6.38(a))

Registered Vehicles (In thousands) = 2000, Trip Rate (motorised) =0.81 (From Figure 6.38(b))

Two Input Variables Case:

The following are the various variable combinations used in the preparation of Nomogram for cities of the area between 300-1000 sq.km.

- Motorized Trip Rate Vs Population Density and City Buses
- Motorized Trip Rate Vs City Buses and Registered Vehicles
- Motorized Trip Rate Vs Population Density and Registered Vehicles

Nomograms prepared for these combinations are presented in Figures 6.39 to 6.41.

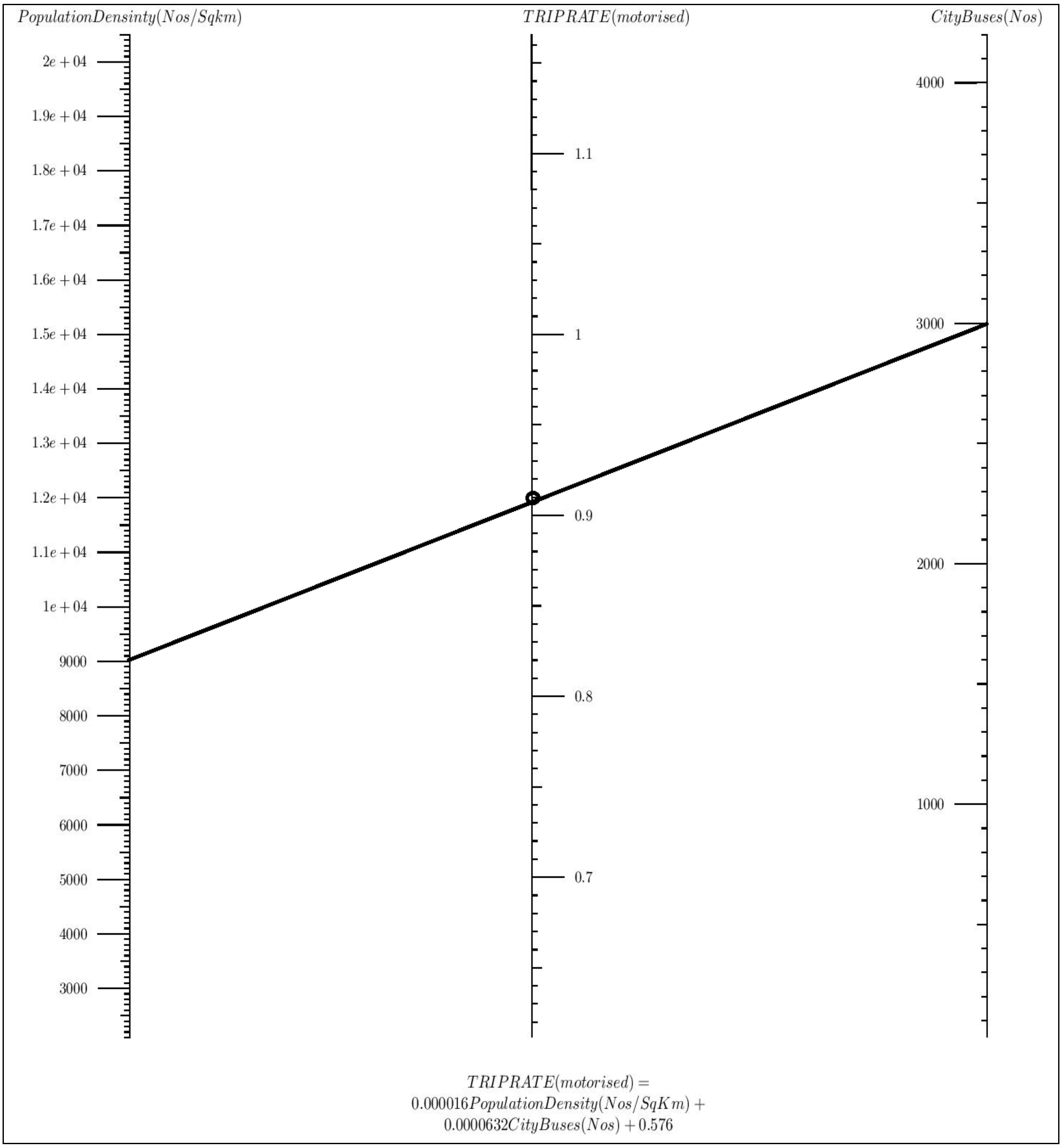


Figure 6.39: Nomograms for Motorized Trip Rate, Population Density and City Buses - CA2

Example: For Population Density (Persons/sqkm) = 9000 and City Buses (In Numbers)= 3000, then Trip Rate (motorised) = 0.91

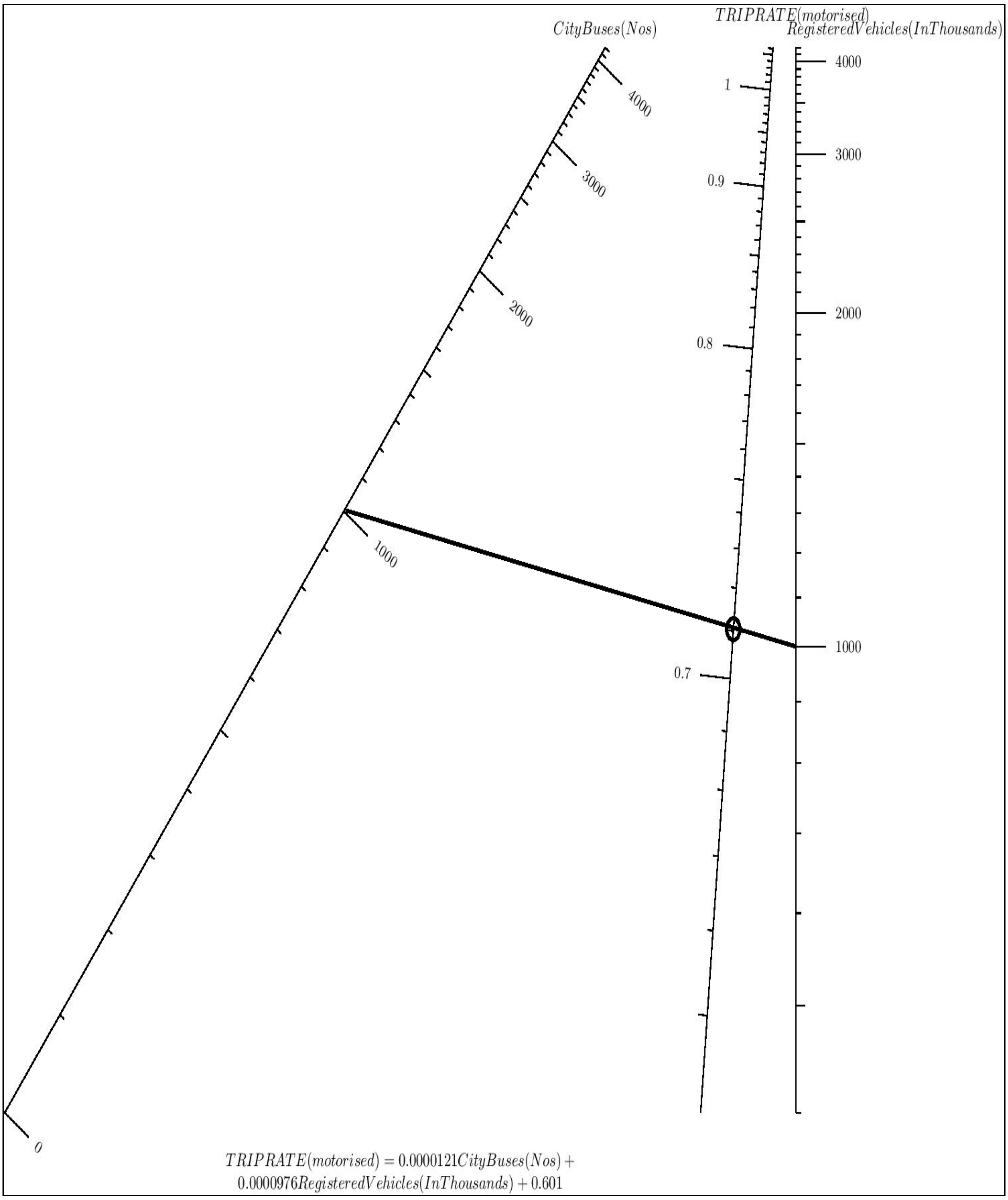


Figure 6.40: Nomograms for Motorized Trip Rate, City Buses and Registered Vehicles - CA2

Example: For City Buses (In Numbers) = 1000 and Registered Vehicles (In thousands)= 1000, then Trip Rate (motorised) = 0.71

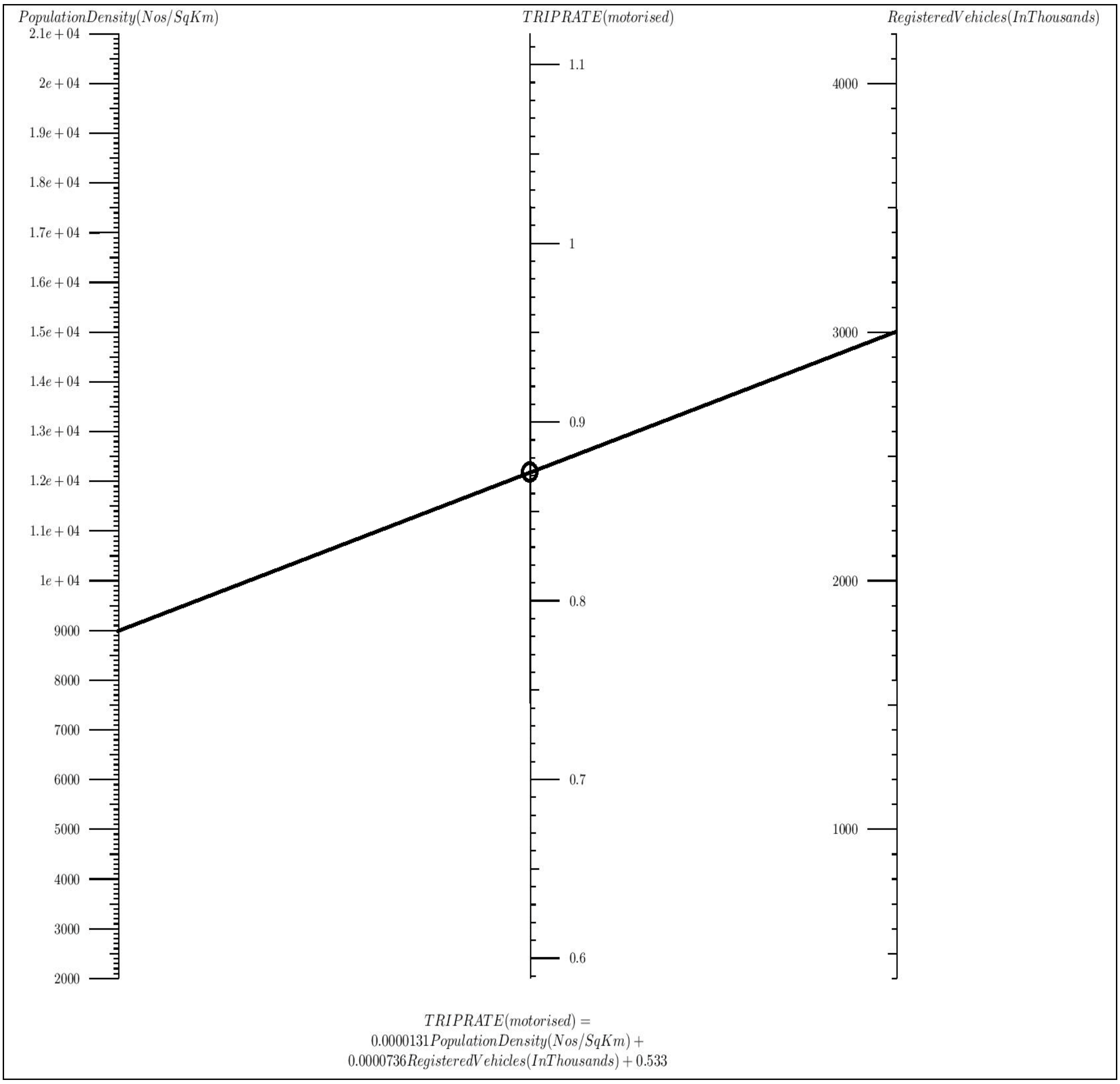


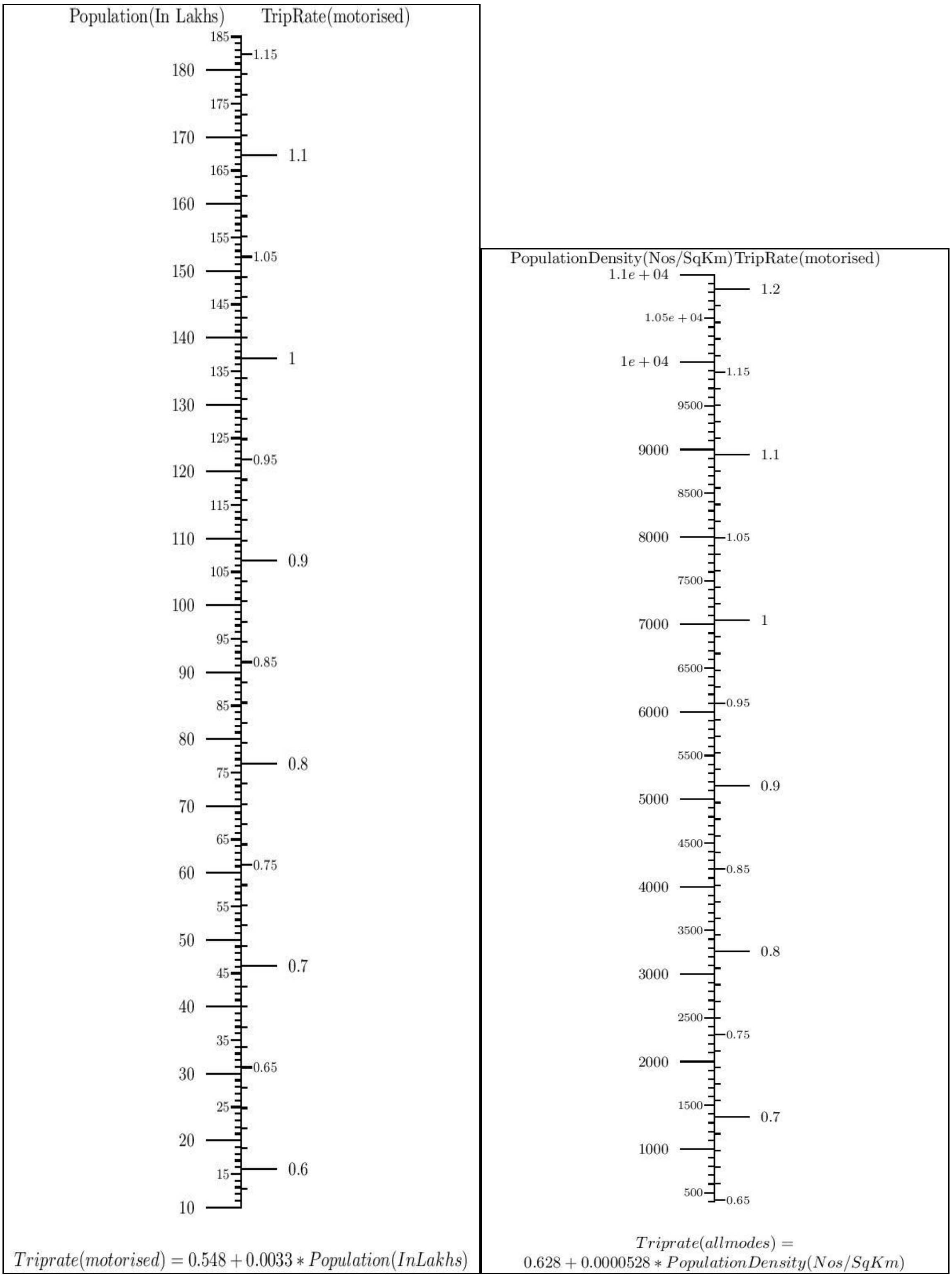
Figure 6.41: Nomograms for Motorized Trip Rate, Population Density and Registered Vehicles - CA2

Example: For Population Density (Persons/sqkm) = 9000 and Registered Vehicles (In thousands)= 3000, then Trip Rate (motorised) = 0.87 (From Figure 6.41)

6.8.3. City Category -CA 3 (City Area >1000 sqkm)

Single Input Variable Case:

Variables like Population, Population Density, City Buses and Registered Vehicles influences Motorized Trip Rate for cities of the area more than 1000 sq.km. Developed nomograms are presented in the Figures 6.42 and 6.43.

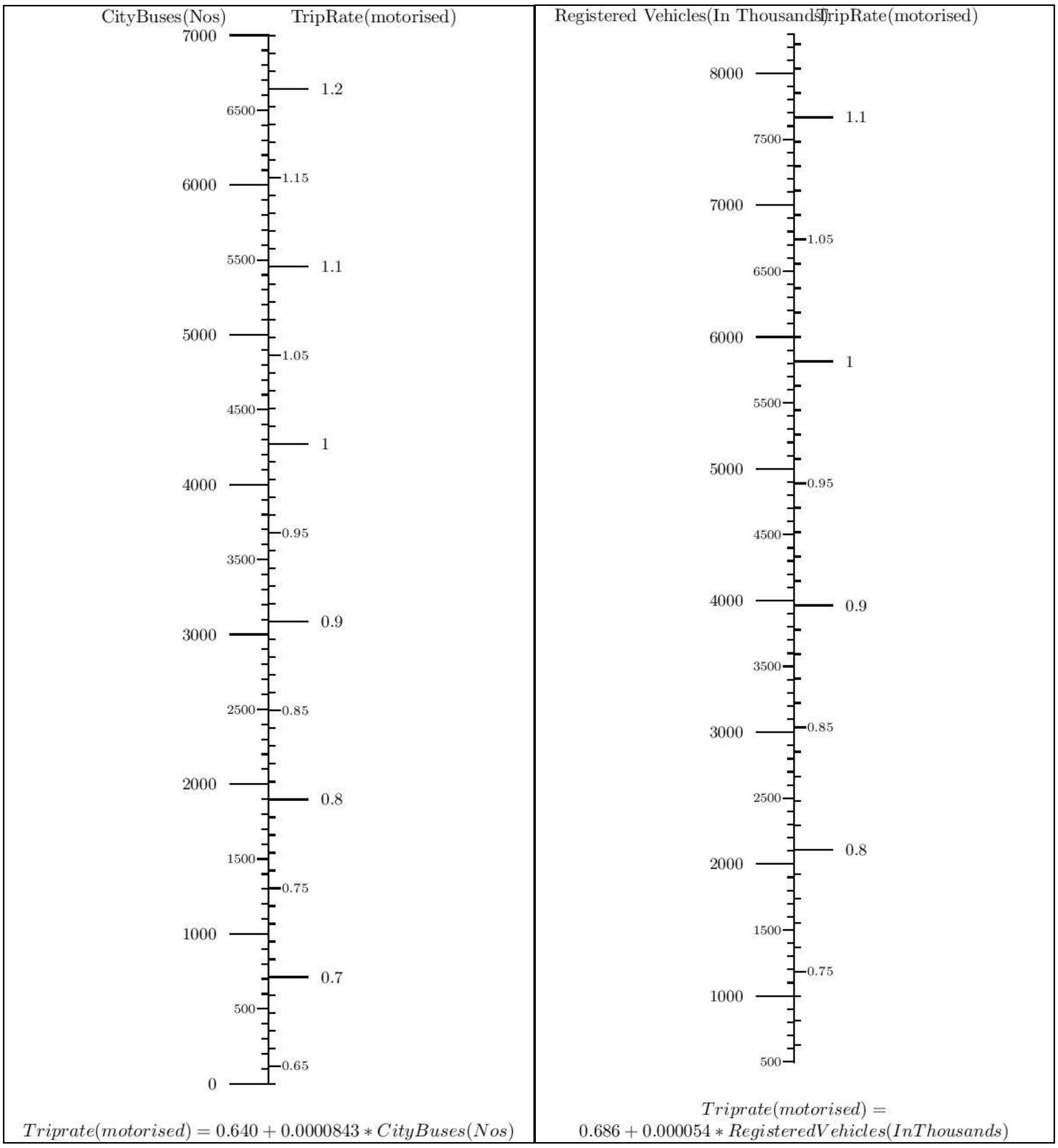


(a) (b)

Figure 6.42: Nomograms for Motorized Trip Rate –Population and Population Density - CA3

Example: Population (In Lakhs) =50, Trip Rate (motorised) = 0.71(From Figure 6.42(a))

Population Density (Persons/Sqkm) = 7000, Trip Rate (motorised) =1.0 (From Figure 6.42(b))



(a) (b)

Figure 6.43: Nomogram for Motorized Trip Rate-City Buses and Registered Vehicle - CA3

Example: City Buses (In Numbers) =2000, Trip Rate (motorised) = 0.81(From Figure 6.43(a))

Registered Vehicles (In thousands) = 6000, Trip Rate (motorised) =1.01 (From Figure 6.43(b))

Two Input Variables Case:

The following are the various variable combinations used in the preparation of Nomogram for big cities of the area more than 1000Sq.km.

- Motorized Trip Rate Vs Population and Population Density
- Motorized Trip Rate Vs Population and City Buses

- Motorized Trip Rate Vs City Buses and Registered Vehicles
- Motorized Trip Rate Vs Population Density and Registered Vehicles

Nomograms prepared for these combinations were presented in the following Figure 6.44 to 6.47.

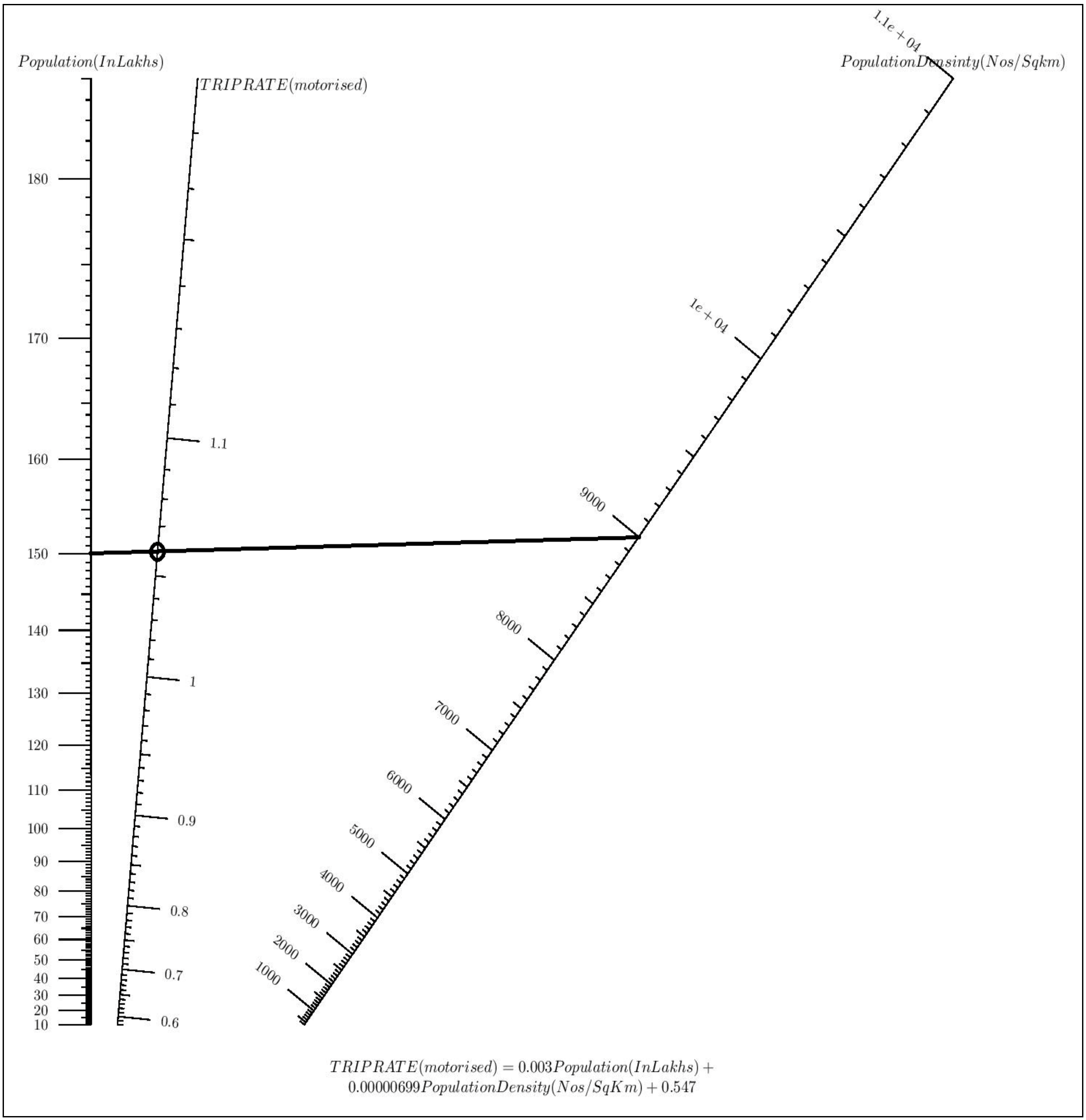


Figure 6.44: Nomogram for Motorized Trip Rate, Population and Population Density - CA3

Example: For Population = 150 lakhs and Population Density (Persons/sqkm) = 9000, then Trip Rate (motorised) = 1.06

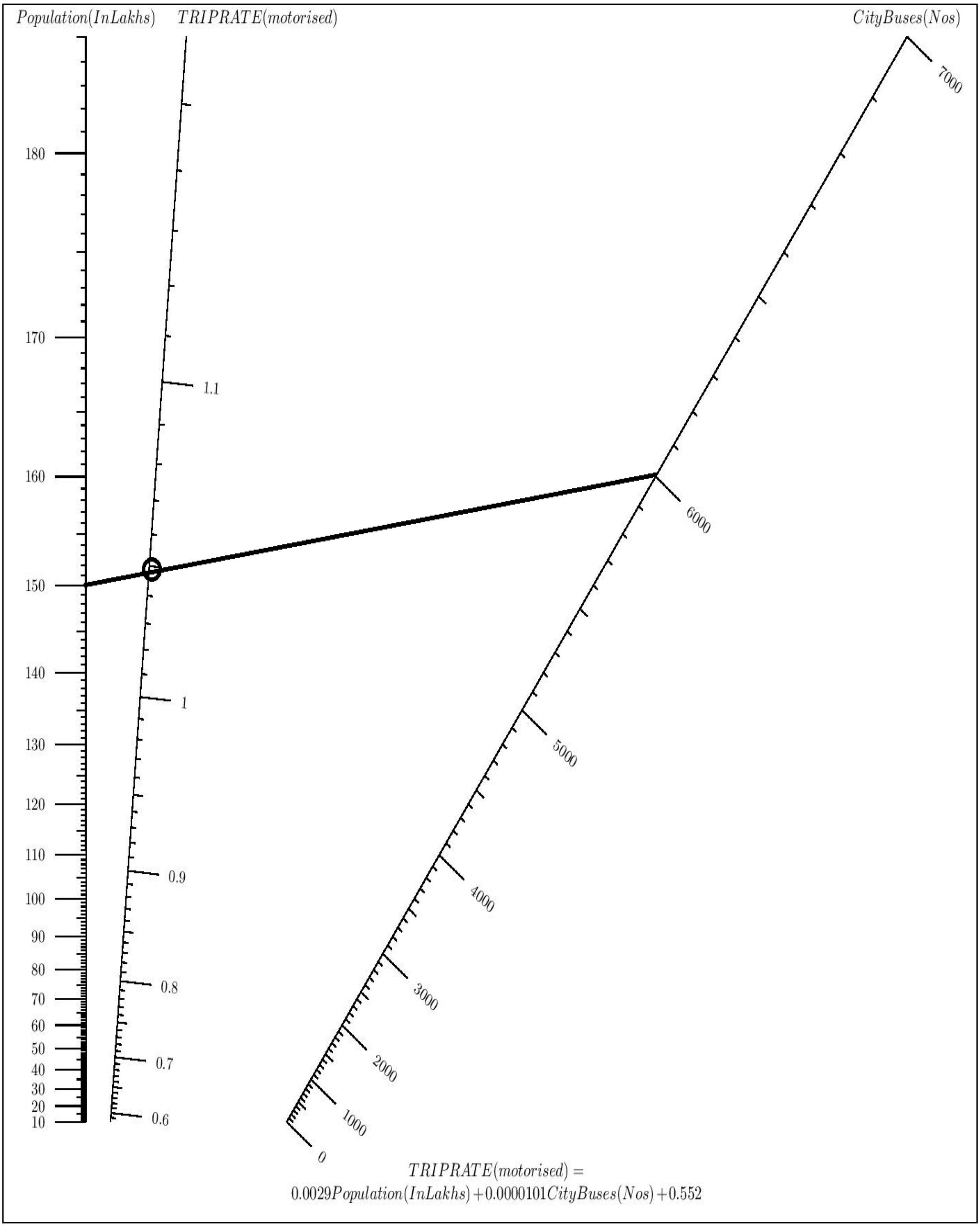


Figure 6.45: Nomogram for Motorized Trip Rate, Population and City Buses - CA3

Example: For Population = 150 lakhs and City Buses = 6000, then Trip Rate (motorised) = 1.05

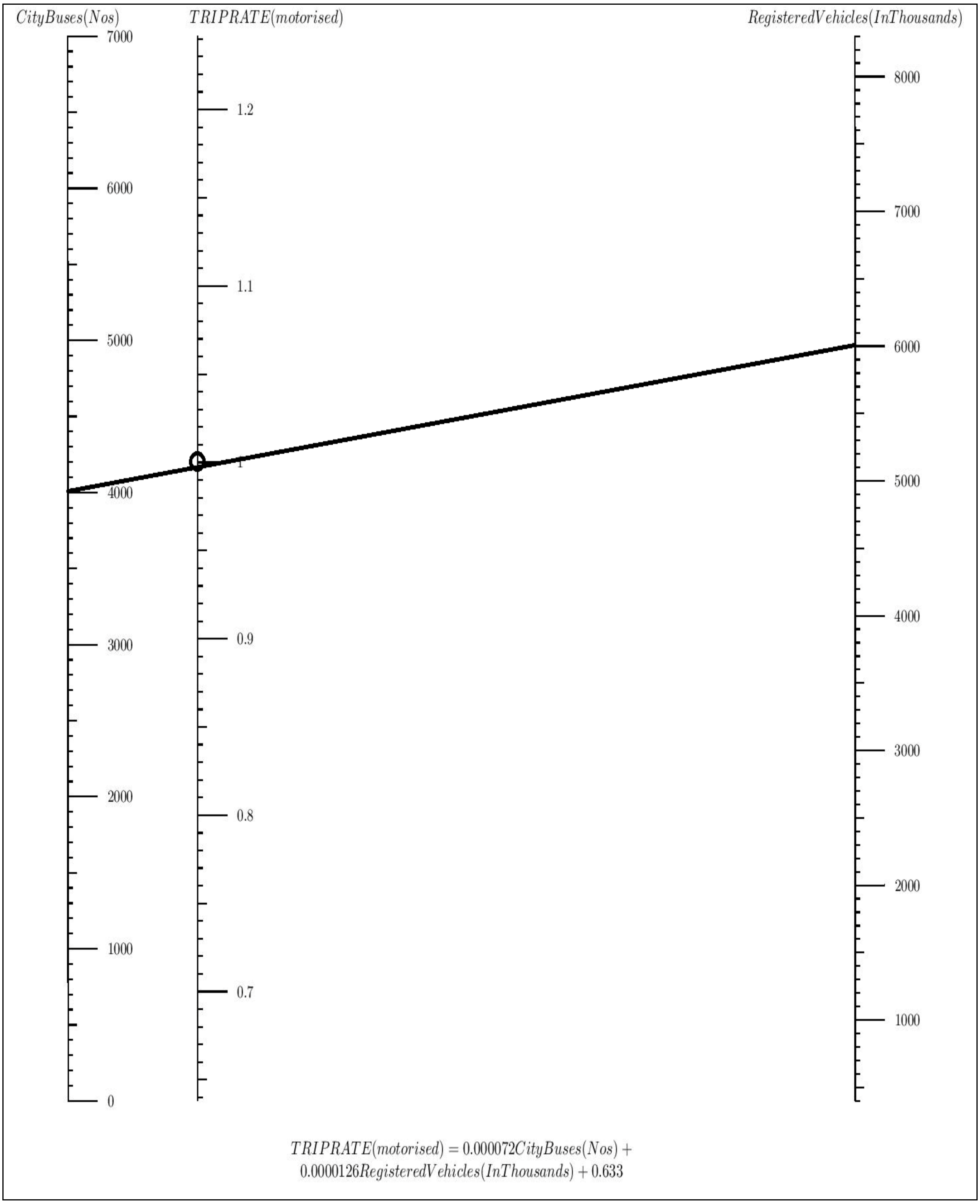


Figure 6.46: Nomogram for Motorized Trip Rate, Population and Registered Vehicles - CA3

Example: For City Buses (In Numbers) = 4000 and Registered Vehicle (In thousands) = 6000, then Trip Rate (motorised) = 1.00

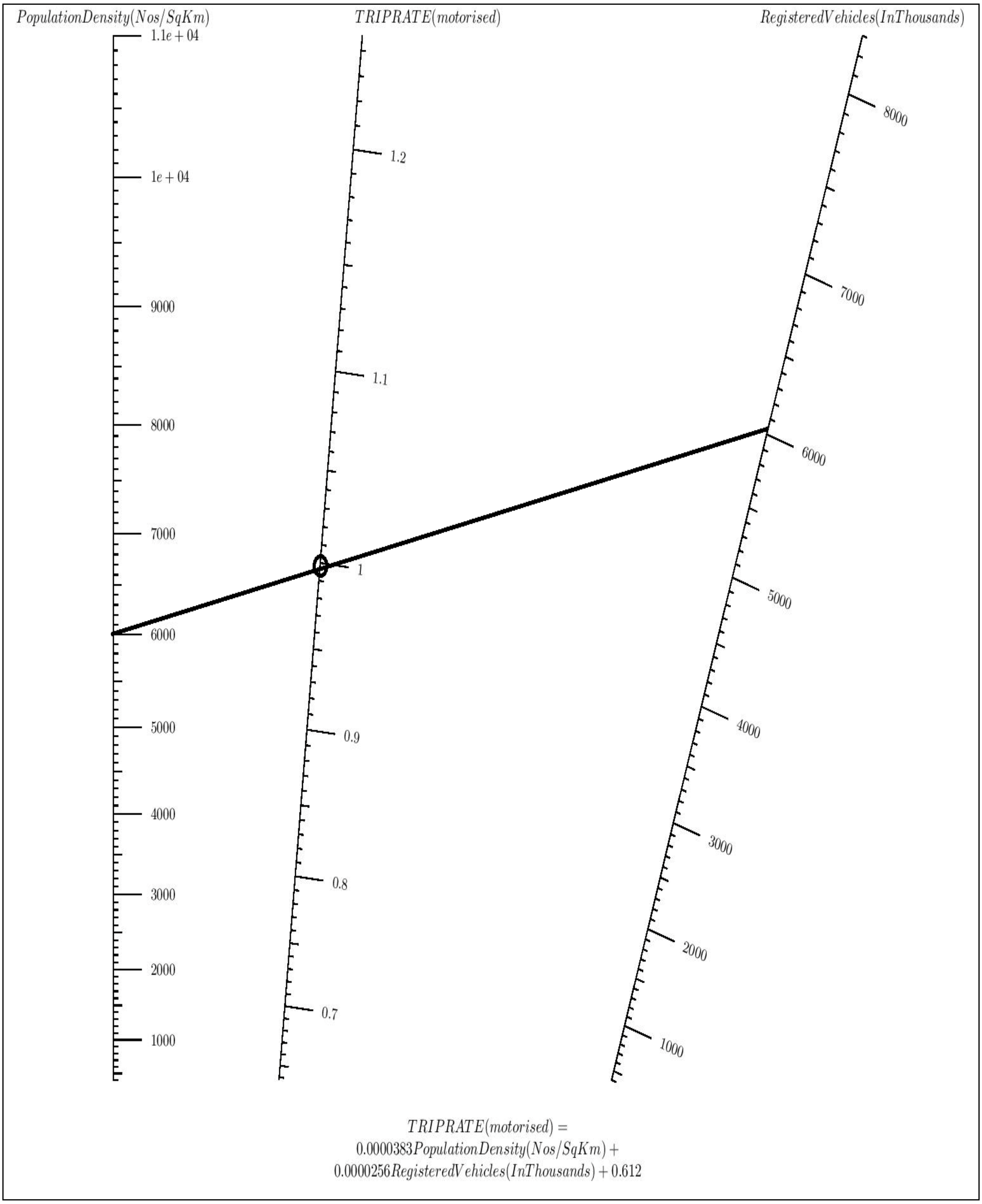


Figure 6.47: Nomogram for Motorized Trip Rate, Population Density and Registered Vehicles - CA3

Example: For Population Density (Persons/sqkm) = 6000 and Registered Vehicle (In thousands) = 6000, then Trip Rate (motorised) = 1.00

6.9. Variation of Trip Rate from Developed Nomograms

Trip rates are found out from the developed Nomograms for various city variables like population, registered vehicles, city buses and per capita income etc. The variation of trip rate with change in population and city area for city category (CP1) are presented in Table 6.6. From this table, it is observed that trip rate varies from 0.826 to 0.978 with population from 1 lakh to 9 lakhs and city area changing from 100 sqkm to 400 sqkm.

Table 6.6: Trip Rates from Nomograms for Population and Area - CP1

Population (In Lakhs)	Trip Rate - CP1			
	Area (sqkm)			
	100	200	300	400
1	0.826	0.830	0.845	0.860
2	0.832	0.846	0.860	0.876
3	0.846	0.861	0.876	0.890
4	0.861	0.875	0.890	0.905
5	0.876	0.890	0.905	0.920
6	0.890	0.905	0.920	0.935
7	0.905	0.920	0.935	0.950
8	0.920	0.935	0.950	0.964
9	0.935	0.950	0.964	0.978

Trip rate from developed Nomograms with population and city buses for city category (CP2) are presented in the Table 6.7. Trip rate ranges from 1.040 to 1.420 with the change of population from 10 lakhs to 40 lakhs and city buses from 100 to 600.

Table 6.7: Trip Rates from Nomograms for Population, Area and City Buses - CP2

Population (In Lakhs)	Trip Rate - CP2					
	City Buses (In Numbers)					
	100	200	300	400	500	600
10	1.040	1.050	1.060	1.075	1.090	1.100
15	1.100	1.110	1.120	1.130	1.140	1.150
20	1.150	1.160	1.170	1.180	1.190	1.205
25	1.205	1.220	1.230	1.240	1.250	1.260
30	1.260	1.270	1.280	1.295	1.305	1.315
35	1.315	1.325	1.340	1.350	1.360	1.370
40	1.370	1.380	1.390	1.400	1.410	1.420

For city category (CP3), trip rates from nomograms are taken for city characteristics and presented in Table 6.8. Table shows that trip rate varies from 1.400 to 1.760 with city area from 1000 sqkm to 4000 sqkm and city buses from 1000 to 7000. Trip rate changes from 1.400 to 1.760 with per capita income from 100,000 to 400,000.

Table 6.8: Trip Rates from Nomograms for various ranges of City Buses, Area and Per Capita Income - CP3

City Buses (In Numbers)	Trip Rate - CP3							
	Area (sqkm)				Per Capita Income(In thousands)			
	1000	2000	3000	4000	100	200	300	400
1000	1.400	1.460	1.520	1.580	1.400	1.450	1.490	1.540
2000	1.430	1.490	1.550	1.610	1.430	1.480	1.530	1.580
3000	1.460	1.520	1.580	1.640	1.470	1.520	1.570	1.610
4000	1.490	1.550	1.610	1.670	1.510	1.560	1.610	1.650
5000	1.520	1.580	1.640	1.700	1.540	1.590	1.640	1.680
6000	1.550	1.610	1.670	1.730	1.570	1.630	1.670	1.720
7000	1.580	1.640	1.700	1.760	1.610	1.660	1.710	1.760

Motorized trip rate values from the nomograms with change in population, registered vehicles and industrial area are presented in Table 6.9. Motorised trip rate fluctuates between 0.405 to 0.524 with population from 2 lakhs to 8 lakhs and industrial area from 1% to 5%. It also changes from 0.401 to 0.566 with registered vehicles from 100,000 to 400,000.

Table 6.9: Motorized Trip Rates from Nomograms for various ranges of Population, Registered Vehicles and Industrial Area - CP1

Industrial Area (Percent)	Motorized Trip Rate - CP1							
	Population (In Lakhs)				Registered Vehicles(In thousands)			
	2	4	6	8	100	200	300	400
1	0.405	0.435	0.460	0.520	0.401	0.434	0.465	0.496
2	0.406	0.438	0.461	0.521	0.420	0.451	0.483	0.515
3	0.407	0.440	0.462	0.522	0.437	0.468	0.500	0.533
4	0.408	0.441	0.463	0.523	0.454	0.484	0.517	0.550
5	0.409	0.442	0.464	0.524	0.471	0.503	0.534	0.566

Motorized trip rates for various population densities and city buses of city category (CP2) is given in Table 6.10. For city category of CP2, Motorized trip rate varies from 0.590 to 0.860 with population density from 5000 persons/sqkm to 25000 persons/sqkm and city buses from 100 to 600.

Table 6.10: Motorized Trip Rates from Nomograms for various ranges of Population Density, City Buses - CP2

Population Density (Persons/sqkm)	Motorized Trip Rate - CP2					
	City Buses (In Numbers)					
	100	200	300	400	500	600
5000	0.590	0.605	0.625	0.645	0.665	0.685
10000	0.630	0.650	0.670	0.690	0.710	0.730
15000	0.675	0.695	0.715	0.735	0.755	0.775
20000	0.720	0.740	0.760	0.780	0.800	0.820
25000	0.760	0.780	0.800	0.820	0.840	0.860

Motorised trip rate of city category (CP3) for city conditions are presented in Table 6.11. This value varies from 0.850 to 1.150 with population from 40 lakhs to 180 lakhs and number of city buses from 1000 to 7000. It also fluctuates from 0.857 to 1.137 with registered vehicles from 20,00,000 to 80,00,000 and for same population change.

Table 6.11: Motorized Trip Rates from Nomograms for various ranges of Population, City Buses and Registered Vehicles- CP3

Population (In Lakhs)	Motorized Trip Rate - CP3							
	City Buses (In Numbers)				Registered Vehicles(In thousands)			
	1000	3000	5000	7000	2000	4000	6000	8000
40	0.850	0.890	0.920	0.950	0.857	0.865	0.876	0.885
60	0.880	0.920	0.950	0.980	0.893	0.908	0.914	0.924
80	0.910	0.950	0.980	1.010	0.928	0.940	0.950	0.960
100	0.940	0.970	1.010	1.040	0.965	0.975	0.985	0.995
120	0.970	1.000	1.040	1.070	1.000	1.010	1.020	1.030
140	0.990	1.030	1.060	1.100	1.037	1.047	1.057	1.067
160	1.020	1.050	1.090	1.125	1.072	1.082	1.092	1.102
180	1.050	1.080	1.120	1.150	1.107	1.117	1.127	1.137

Trip rate for different city conditions of city category (CA1) is given in Table 6.12. Trip rate ranges of city category (CA1) from 0.876 to 1.301 with population from 5 lakhs to 30 lakhs and registered vehicles from 10,000 to 110,000. For the same city category and range of registered vehicles, trip rate varies from 0.837 to 1.155 with per capita income from Rs. 20,000 to Rs. 100,000.

Table 6.12: Trip Rates from Nomograms for various ranges of Population, Per Capita Income and Registered Vehicles- CA1

Registered Vehicles(In thousands)	Trip Rate - CA1										
	Population (In Lakhs)						Per Capita Income (In thousands)				
	5	10	15	20	25	30	20	40	60	80	100
10	0.876	0.955	1.045	1.124	1.210	1.296	0.837	0.912	0.982	1.060	1.120
30	0.877	0.957	1.046	1.126	1.212	1.297	0.844	0.918	0.992	1.065	1.130
50	0.878	0.959	1.047	1.128	1.214	1.298	0.848	0.923	0.996	1.070	1.140
70	0.879	0.961	1.048	1.130	1.216	1.299	0.853	0.928	1.000	1.075	1.150
90	0.880	0.963	1.049	1.132	1.218	1.300	0.858	0.930	1.005	1.080	1.155
110	0.881	0.967	1.050	1.134	1.219	1.301	0.862	0.935	1.010	1.085	1.160

Trip rate found from nomograms for various city conditions of city category (CA2) is shown in Table 6.13. Trip rates gathered from nomograms changes from 1.128 to 1.535 with population density from 3000 persons/sqkm to 18000 persons/sqkm and registered vehicles from 10,00,000 to 40,00,000. It also varies from 1.150 to 1.562 with city buses from 1000 to 4000 and for same range of population density.

Table 6.13: Trip Rates from Nomograms for various ranges of Population Density, Registered Vehicles and City Buses- CA2

Population Density(Persons/sqkm)	Trip Rate - CA2							
	Registered Vehicles (In thousands)				City Buses (In Numbers)			
	1000	2000	3000	4000	1000	2000	3000	4000
3000	1.128	1.172	1.218	1.262	1.150	1.190	1.231	1.270
6000	1.180	1.228	1.272	1.318	1.209	1.250	1.288	1.330
9000	1.232	1.280	1.328	1.372	1.268	1.308	1.348	1.388
12000	1.288	1.332	1.380	1.428	1.328	1.368	1.408	1.448
15000	1.342	1.388	1.435	1.480	1.382	1.425	1.465	1.505
18000	1.395	1.440	1.488	1.535	1.442	1.482	1.522	1.562

Trip rates for various city conditions and city category (CA3) are presented in Table 6.14. These values ranges from 1.258 to 1.670 with registered vehicles from 10,00,000 to 80,00,000 and city buses from 1000 to 6000. The same varies from 1.220 to 1.668 with population density from 1000 persons/sqkm to 9000 persons/sqkm and for the same registered vehicles change.

Table 6.14: Trip Rates from Nomograms for various ranges of Registered Vehicles, City Buses and Population Density- CA3

Registered Vehicles(In thousands)	Trip Rate - CA3										
	City Buses (In Numbers)						Population Density(Persons/sqkm)				
	1000	2000	3000	4000	5000	6000	1000	3000	5000	7000	9000
1000	1.258	1.322	1.390	1.455	1.520	1.590	1.220	1.290	1.358	1.428	1.492
2000	1.270	1.338	1.402	1.470	1.535	1.600	1.248	1.315	1.382	1.450	1.518
3000	1.282	1.348	1.418	1.480	1.545	1.618	1.270	1.340	1.408	1.475	1.542
4000	1.295	1.360	1.428	1.492	1.560	1.625	1.295	1.362	1.430	1.500	1.570
5000	1.308	1.372	1.440	1.505	1.575	1.640	1.322	1.388	1.458	1.525	1.592
6000	1.318	1.385	1.450	1.518	1.582	1.650	1.345	1.415	1.482	1.550	1.618
7000	1.328	1.395	1.462	1.530	1.595	1.660	1.370	1.440	1.508	1.575	1.642
8000	1.340	1.408	1.475	1.540	1.610	1.670	1.395	1.462	1.532	1.600	1.668

Motorized trip rates found from the nomograms for various city conditions of city category (CA1) is given in Table 6.15. This trip rate value fluctuates from 0.488 to 0.870 with population density from 5000 persons/sqkm to 25000 persons/sqkm and numbers of city buses from 100 to 600.

Table 6.15: Motorized Trip Rates from Nomograms for various ranges of City Buses and Population Density- CA1

Population Density (Persons/sqkm)	Motorized Trip Rate - CA1					
	City Buses (In Numbers)					
	100	200	300	400	500	600
5000	0.488	0.512	0.540	0.568	0.595	0.622
10000	0.588	0.598	0.622	0.668	0.678	0.705
15000	0.652	0.680	0.708	0.732	0.762	0.790
20000	0.732	0.762	0.788	0.818	0.842	0.868
25000	0.808	0.862	0.870	0.898	0.925	0.952

Motorized trip rate collected from the nomogram for various city conditions of city category (CA2) is presented in Table 6.16. These values are fluctuating from 0.648 to 1.062 with population density from 3000 persons/sqkm to 18000 persons/sqkm and registered vehicles from 10,00,000 to 40,00,000. It changes from 0.685 to 1.112 with number of city buses from

1000 to 4000 and for same population density variation. Motorised trip rate ranges between 0.712 and 1.040 with same variation of number of city buses and registered vehicles.

Table 6.16: Motorized Trip Rates from Nomograms for various ranges of Registered Vehicles, City Buses and Population Density- CA2

Population Density(Persons/sqkm)	Motorized Trip Rate - CA2							
	Registered Vehicles (In thousands)				City Buses (In Numbers)			
	1000	2000	3000	4000	1000	2000	3000	4000
3000	0.648	0.718	0.792	0.862	0.685	0.748	0.810	0.872
6000	0.685	0.758	0.832	0.905	0.732	0.795	0.858	0.920
9000	0.722	0.798	0.872	0.945	0.782	0.845	0.908	0.968
12000	0.762	0.838	0.910	0.985	0.830	0.890	0.955	1.018
15000	0.802	0.872	0.950	1.022	0.862	0.940	1.005	1.062
18000	0.840	0.918	0.988	1.062	0.922	0.988	1.050	1.112
City Buses (In Numbers)	Registered Vehicles (In thousands)							
	1000	2000	3000	4000				
1000	0.712	0.808	0.902	1.000				
2000	0.722	0.820	0.918	1.015				
3000	0.732	0.832	0.930	1.025				
4000	0.748	0.842	0.940	1.040				

Motorized trip rate found from nomograms for different city conditions of city category (CA3) is given in Table 6.17. Motorized trip rate changes from 0.580 to 1.098 with Population density from 1000 persons/sqkm to 10000 persons/sqkm and Population from 10 lakhs to 160 lakhs. These values varies between 0.590 to 1.088 with number of city buses from 1000 to 7000 and for same population range. Motorized trip rate changes from 0.678 to 1.175 with population density from 1000 persons/sqkm to 10000 persons/sqkm and registered vehicles from 10,00,000 to 70,00,000. It is also ranging between 0.718 to 1.225 with number of city buses from 1000 to 7000 and for same variation of registered vehicles.

Table 6.17: Motorized Trip Rates from Nomograms for various ranges of Population, City Buses and Population Density and Registered Vehicles - CA3

Population (In Lakhs)	Motorized Trip Rate - CA3							
	Population Density(Persons/sqkm)				City Buses (In Numbers)			
	1000	3000	7000	10000	1000	3000	5000	7000
10	0.580	0.610	0.640	0.660	0.590	0.620	0.640	0.650
40	0.670	0.690	0.720	0.740	0.680	0.700	0.725	0.750
70	0.760	0.780	0.810	0.830	0.760	0.790	0.810	0.830

Population (In Lakhs)	Motorized Trip Rate - CA3							
	Population Density(Persons/sqkm)				City Buses (In Numbers)			
	1000	3000	7000	10000	1000	3000	5000	7000
100	0.850	0.870	0.895	0.920	0.850	0.870	0.892	0.915
130	0.940	0.955	0.985	1.008	0.938	0.948	0.978	1.000
160	1.030	1.048	1.075	1.098	1.025	1.048	1.068	1.088
Registered Vehicles (In thousands)	Population Density(Persons/sqkm)				City Buses (In Numbers)			
	1000	3000	7000	10000	1000	3000	5000	7000
1000	0.678	0.750	0.905	1.020	0.718	0.860	1.002	1.148
3000	0.728	0.800	0.958	1.072	0.742	0.888	1.030	1.172
5000	0.778	0.850	1.008	1.022	0.768	0.912	1.058	1.200
7000	0.828	0.905	1.058	1.175	0.790	0.935	1.080	1.225

6.10. Nomograms Validation

Based on one input and two input variables Nomograms, Trip Rates are predicted for validation data given Table 5.9. Prediction errors were estimated by subtracting predicted trip rate of Nomogram and actual trip rate. Mean Square Error (MSE) is calculated based on these errors of individual cities of validation data. Mean Square Errors (MSE) for various Nomograms were presented in Table 6.18. It varies from 0.00 to 0.09 as shown in the Table.

Table 6.18: Nomograms for Various City Categories - Validation (MSE)

CP 1		**CP 2**		**CA 1**		**CA 2**	
Figure ID	MSE	Figure ID	MSE	Figure ID	MSE	Figure ID	MSE
Figure 6.2 a	0.02	Figure 6.5 a	0.06	Figure 6.21 a	0.06	Figure 6.25 a	0.01
Figure 6.2 b	0.01	Figure 6.15 b	0.01	Figure 6.22 a	0.09	Figure 6.26 b	0.05
Figure 6.11 a	0.04	Figure 6.6	0.03	Figure 6.35	0.02	Figure 6.37 a	0.02
Figure 6.4	0.01	Figure 6.16	0.01	Figure 6.36	0.01	Figure 6.38 a	0.08
						Figure 6.28 b	0.02
						Figure 6.39	0.05

6.11. Summary

Cities data has been categorized based on population and city area ranges. Various equations were formulated by examining correlation matrices for different city categories. Pynomo nomenclature has been discussed to get a clear understanding of the Pynomo scripts. Type 1 and Type 8 of the Pynomo Nomogram scripts were modified as per the developed models for various categories. Thus, corresponding Nomograms were developed. Nomogram validation based on Mean Square Error is also discussed in this chapter.

Chapter 7
Summary and Conclusions

7.1. Summary

Travel demand modelling is necessary for assessing the travel requirements of the commuters. The per capita trip rate in line with the decision-making process of travel infrastructure is also required. The trip rate is defined as the number of trips generated per person per day.

Trip generation is one of the vital steps of transportation planning. Ma et al. (1999) have significantly kept effort in the field of activity generation by using the Poisson model but concluded that its assessment is not satisfied. Bhat et al. (1998) worked on the frequency of shopping activities at household level through count data model. Models were prepared for the trip generation at city level using either multiple linear regression analysis or cross-classification/category analysis. Of these two, the cross-classification analysis is more universally adopted (McNally 2000) with applications in passenger travel (Guevara et al. 2007) and also freight (Bastida et al. 2009). These methods are detailed in various documents (Meyer et al. 2000, Ortuzar 2001). There were various studies conducted using regression models for trip generation (Neumann et al. 1983; Washington 2000; Yam et al. 2000; Kwigizile et al. 2009; Ewing et al. 2011). A multiple linear regression model was developed to assess traffic generation to high density, large scale, multi-story public residential accommodation estates in Hong Kong (Yam et al. 2000). In spite of various works conducted in the field of trip generation, there is a scope for further improvement. In this work, an application of concepts like regression analysis, artificial neural networks (ANN), principal component analysis were studied. A quick estimation mechanism was also worked by constructing nomograms.

Data of twenty six cities was collected from various sources. Based on population, Cities are categorized as three types as indicated below.

- CP1: Population of City < 10 lakhs
- CP2: Population of City between 10 to 40 lakhs
- CP3: Population of City > 40 lakhs

Based on city area, Cities are also categorized into three types as indicated below.

- CA1: Area of City < 300 sq.km
- CA2: Area of City between 300 to 1000 sq.km
- CA3: Area of City > 1000 sq.km

Land-use and socio-economic variables are considered for studying trip rate. Socio-economic variables considered are Population, Area, Population Density, Per capita Income, City Buses, Male (%), Female (%), Road Safety Index, Road Density and Registered vehicles. Land-Use variables considered are Residential (%), Commercial (%), Industrial (%), Public (%), Recreational (%) and Transport (%), etc.

Regression models were formed for trip rate with city area, population, registered vehicles, per-capita income and city buses independently. Similar models were also formed for motorized trip rate with population, registered vehicles, per-capita income and city buses independently. As trip length is also a vital parameter, attempts were made to develop models for the same. Trip length models were developed with city area, population, population density, registered vehicles, per-capita income and city buses.

Multiple linear regression (MLR) models were also developed for trip rate in combination with city area, population, population density, registered vehicles and city buses for various city categories mentioned above. MLR models were developed for motorized trip rate in combination of city area, population, population density, registered vehicles, city buses and industrial area (%) for various city categories mentioned above.

Typical Multiple Linear Regression (MLR) models are given below:

t-stat for the models are presented in brackets.

For All Cities Data:

- Trip Rate = 0.0041*Population + 0.0099*Industrial Area(%)+0.98

(23.36) (1.29) (23.36)

R-Square = 0.78;

For CP1 Category of Cities:

- Trip Rate = 0.00015*City Area + 0.0146*Population + 0.787

(0.57) (1.60) (22.68)

R-Square = 0.81;

For CP2 Category of Cities:

- Trip Rate = 0.0108*Population + 0.000103*City Buses + 0.928

  (3.19) (0.92) (14.0)

R-Square = 0.63;

For CP3 Category of Cities:

- Trip Rate = 6.1x10-5*City Area + 2.94x10^{-5}*City Buses + 1.31

  (3.44) (2.74) (36.31)

R-Square = 0.83;

For CA1 Categories of Cities:

- Trip Rate = 0.0169* Population + 5x10^{-5}*Registered Vehicle + 0.79

  (5.43) (0.54) (22.82)

  R-Square = 0.89;

For CA2 Categories of Cities:

- Trip Rate =1.95x10-5*Population Density + 3.9x10-5*City Buses+1.053

  (3.39) (1.72) (18.04)

R-Square = 0.85;

For CA3 Categories of Cities:

- Trip Rate = 3.4x10-5*Population Density+2.4x10-5*Registered Vehicles + 1.16

  (1.36) (0.86) (10.5)

R-Square = 0.70;

As the input parameter matrix size is big, to reduce the dimensionality of this matrix principal component analysis concept was applied. Eigen values were calculated for the given data set. First five principal components explain 70% data variability. Parameters influencing principal components are given in Table 7.1.

Table 7.1: Highly correlated parameters for Principal Components

Principal Component	Variability Explained (%)	Variables Correlated
PC 1	22.27	Area, Population, Per Capita Income, City Buses, Registered Vehicles
PC 2	16.46	Male (%), Female (%) and Public Area (%)
PC 3	14.32	Transport Area (%), Agricultural Area (%)
PC 4	10.33	Commercial Area (%)
PC 5	9.12	Population Density

MLR Models with principal components were are also given below.

For All cities data:

Trip Rate = 0.088*PC1-0.023*PC2+0.056*PC3+0.044*PC4-0.03*PC5+1.204

(10.7) (-2.38) (5.50) (3.69) (-2.82) (69.0)

R-Square = 0.89;

For CP1 Category of Cities:

- Trip Rate = 0.018*PC1+0.018*PC2+0.021*PC3-0.013*PC4-0.02*PC5+0.89

(65535) ((65535) (65535) (65535) (65535) (65535)

R-Square = 1.00;

For CP2 Categories of Cities:

- Trip Rate = -0.013*PC1+0.026*PC2+0.0046*PC3+0.007*PC4-0.008*PC5+1.16

(-1.03) (1.71) (0.25) (0.34) (0.39) (37.1)

R-Square = 0.46;

For CP3 Categories of Cities:

- Trip Rate = 0.034*PC1-0.013*PC2-0.04*PC3-0.014*PC4-0.025*PC5+1.47

(4.29) (-1.49) (-3.56) (-1.04) (-1.67) (1.47)

R-Square = 0.92;

For CA1 Categories of Cities:

- Trip Rate = -0.05*PC1-0.04*PC2+0.025*PC3-0.009*PC4-6.7X10^{-5}*PC5+1.04

(-6.28) (-3.61) (1.84) (-0.62) (-0.003) (46.5)

R-Square = 0.90;

For CA2 Categories of Cities:

- Trip Rate = 0.041*PC1+0.015*PC2+0.057*PC3-0.018*PC4+0.017*PC5+1.31

(6.10) (1.81) (6.82) (-1.49) (1.30) (77.67)

R-Square = 0.98;

For CA3 Categories of Cities:

- Trip Rate = -0.05*PC1+0.046*PC2-0.075*PC3-0.037*PC4-0.009*PC5+1.38

(65535) (65535) (65535) (65535) (65535) (65535)

R-Square = 1.00;

In order to develop better models, Artificial Neural Networks (ANN) is applied to data set. Artificial Neural Network is applied to input parameters illustrated above with trip rate as target data. Data was divided into Training, Validation and Testing data set in the ratio of 70:15:15. Land use and trip rate was processed through ANN. It reveals that Trainlm has better performance (R-Value) followed by Traincgf and Trainbfg. Trainlm training function was used for the ANN for all the combinations of cities data, i.e., combined and categorized city data. ANN structure of 20:20:1 is adopted for city categories based on population and city area. The network structure with total data and trip rate are shown in Figure 7.1. Training results for this network is presented in Table 7.2. Five principal component data was also used as input to ANN for all combinations of cities data. ANN structure adopted for these combinations is 5:5:1. R-Values and Mean Square Error (MSE) were found for these combinations.

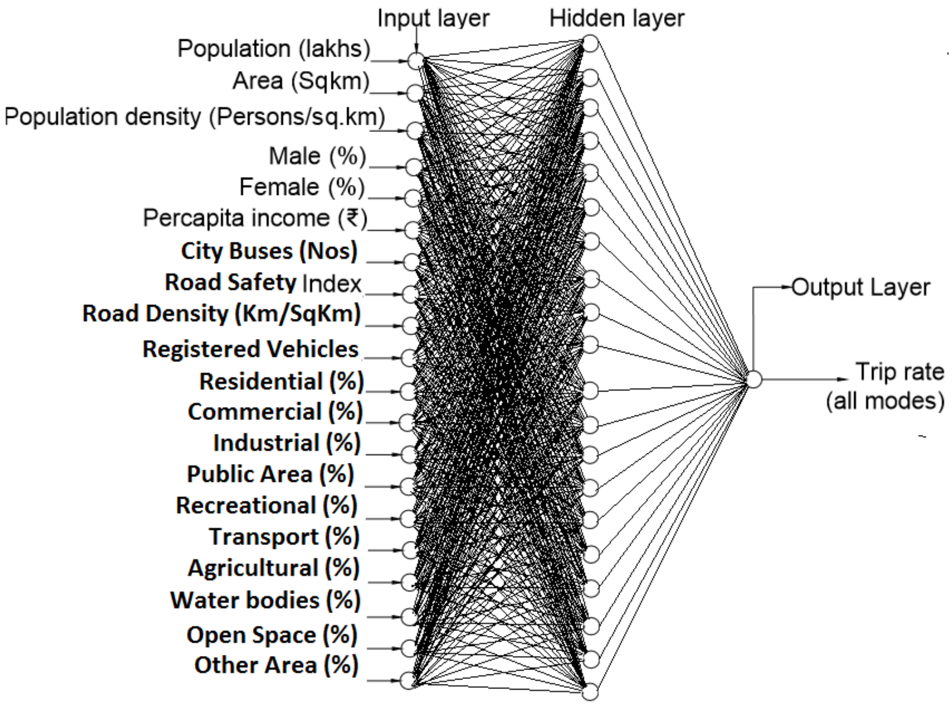


Figure 7.1: Network Architecture for Socio-economic and Land use Parameter vs. Trip Rate

Table 7.2: Training Results of the ANN (with Total Inputs)-Trip Rate

Back Propagation with Trainlm (Total Input data)		
Overall (R)	MSE	Epoch
0.950	0.015	2

This study also focuses on the development of Nomograms for quick estimation of Trip Rate and motorized trip rate. Pynomo is used to construct Nomograms for the trip rate. Pynomo is a one of the modules of Python programming. Various types of scripts are available to create Nomograms of different types. Type 8 script was used to develop single input variable

Nomogram. Type 1 script was used to develop two input variable Nomogram. These Nomograms were developed for various city categories based on population and city area. A sample Nomogram is given in Figure 7.2.

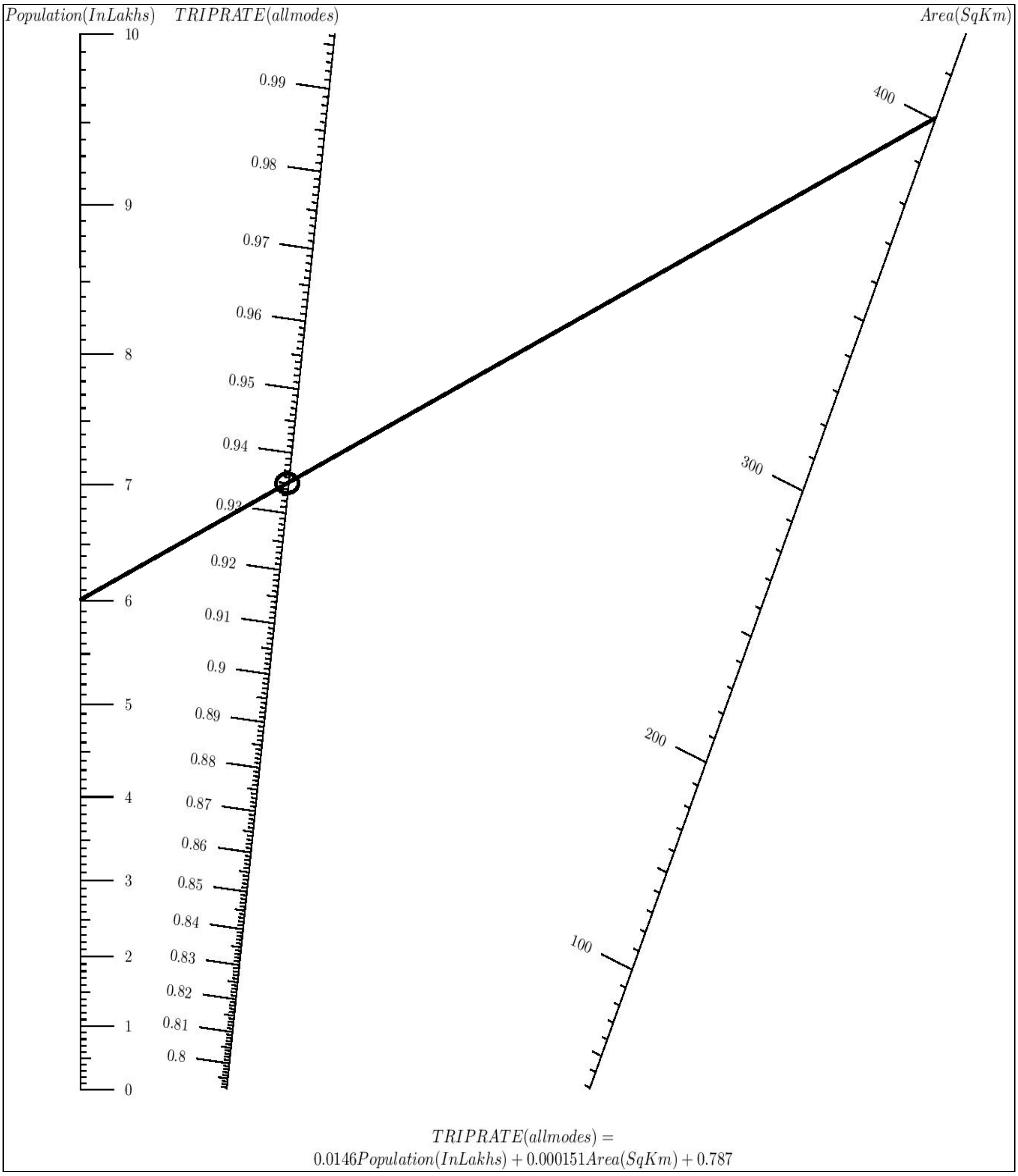


Figure 7.2: Nomogram between Trip Rate, Population and Area - CP1

Example: For Population (In Lakhs) = 6 and Area (Sqkm)= 400, then Trip Rate = 0.935

7.2. Conclusions

Following conclusions have been drawn from this thesis work,

1. Trip rate increase with population size and this increase is steep up to a population of 40 lakhs. There is an abrupt change around 40 lakhs and increase in trip rate is found to be nominal, beyond 40 lakh population. The rate of increase of Trip Rate is 0.40, 0.22 and 0.06 for less than 10 lakhs, 10 to 40 lakhs and more than 40 lakhs respectively.
2. The trip length of the city increases with the increase in population size and the rate of increase of trip length is 0.514 per lakh population.
3. Regression analysis revealed that city population is found to be the significant variable in explaining Trip Rate. Next to population, Registered Vehicles and Number of city buses are major contributing variables in explaining Trip Rate and Motorized Trip Rate.
4. Principal components have exhibited in developing better trip rate models compared to the original data regression models.
5. The training function TRAINLM has performed well using the Feed Forward Back Propagation algorithm producing a predicted trip rate value.
6. Trip rate models developed using ANN were found to have better explanatory power compared to regression models. ANN models observed to have higher correlation coefficient and lesser Mean Square Error compared to Regression models.
7. PCs with ANN combination models produce superior correlation coefficient and insignificant Mean Square Errors (MSE).
8. Based on Mean Square Error (MSE), it is observed that categorization of cities yielded better results in case of ANN models.

7.3. Limitations of the Present Work

In spite of various findings from the work, following are the limitations of the present study,

- Out of 500 Indian cities having population more than 1 lakh, similar type of data is available for limited cities.

- This work has not investigated the intensity of land use activity on trip rates, due to lack of data.

7.4. Scope for Further Study

Even though work has explored linear regression, principal component analysis, and artificial neural network, there is a scope for improvement in the estimation of Trip Rate. The scope of the further study is listed below.

- Variables like employment, number of industries could be considered for further study
- A detailed location level Trip generation rates can be explored.

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ANNEXURE

Annexure 1a: Correlation Matrix of CP1

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
A	1.00																					
B	0.82	1.00																				
C	-0.28	0.20	1.00																			
D	0.07	0.48	0.25	1.00																		
E	-0.07	-0.29	0.21	-0.64	1.00																	
F	0.13	0.39	-0.13	0.75	-0.98	1.00																
G	0.33	0.71	0.46	0.53	-0.58	0.66	1.00															
H	0.29	0.09	-0.79	0.15	-0.75	0.67	0.11	1.00														
I	-0.71	-0.76	0.33	-0.45	0.68	-0.67	-0.51	-0.65	1.00													
J	0.89	0.94	0.08	0.21	-0.09	0.15	0.51	0.05	-0.73	1.00												
K	-0.48	-0.40	-0.09	-0.24	-0.31	0.13	-0.10	0.25	-0.06	-0.30	1.00											
L	-0.61	-0.50	0.65	-0.39	0.71	-0.69	-0.25	-0.87	0.91	-0.47	-0.03	1.00										
M	0.37	0.72	0.29	0.79	-0.67	0.79	0.90	0.24	-0.57	0.45	-0.33	-0.42	1.00									
N	0.15	0.52	0.11	0.78	-0.93	0.96	0.80	0.50	-0.68	0.28	0.13	-0.58	0.87	1.00								
O	0.20	0.63	0.43	0.91	-0.38	0.50	0.49	-0.13	-0.45	0.44	-0.27	-0.26	0.68	0.61	1.00							
P	-0.17	0.02	-0.19	0.28	-0.88	0.78	0.45	0.68	-0.49	-0.10	0.68	-0.49	0.37	0.75	0.04	1.00						
Q	0.82	0.56	-0.34	-0.05	-0.10	0.17	0.37	0.38	-0.44	0.55	-0.59	-0.47	0.42	0.13	-0.11	-0.11	1.00					
R	0.79	0.34	-0.48	-0.45	0.38	-0.35	-0.17	0.17	-0.23	0.52	-0.51	-0.29	-0.15	-0.41	-0.34	-0.47	0.79	1.00				
S	0.59	0.11	-0.69	-0.19	0.19	-0.14	-0.32	0.36	-0.14	0.17	-0.63	-0.39	-0.09	-0.31	-0.27	-0.42	0.73	0.83	1.00			
T	-0.38	-0.39	0.39	-0.18	0.82	-0.75	-0.57	-0.82	0.78	-0.34	-0.37	0.77	-0.49	-0.72	-0.01	-0.83	-0.41	-0.06	0.01	1.00		
U	0.81	0.89	-0.01	0.60	-0.25	0.38	0.46	0.16	-0.70	0.81	-0.62	-0.59	0.66	0.42	0.70	-0.17	0.58	0.41	0.39	-0.22	1.00	
V	0.48	0.82	0.67	0.48	0.07	0.07	0.62	-0.47	-0.29	0.73	-0.51	0.05	0.60	0.28	0.72	-0.32	0.24	0.08	-0.15	0.12	0.71	1.00

Note: A- Area(sqkm); B-Population (In Lakhs); C- Population Density(Persons/sqkm); D-PerCapita Income(Rs); E- Male%; F- Female%; G-City Buses(Nos); H- Road Safety Index; I- Road Density ; J- Registered Vehicles; K- Residential(%); L- Commercial(%); M- Industrial(%); N- Public & Semi Public; O- Recreational(%); P- Transport(%); Q- Agricultural(%); R- Water bodies(%); S- Open Spaces(%); T- Others(%); U- Trip Rate; V- Motorized Trip Rate

Annexure 1b: Correlation Matrix of CP2

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
A	1.00																					
B	0.00	1.00																				
C	-0.62	0.58	1.00																			
D	0.61	0.63	-0.14	1.00																		
E	0.54	0.24	-0.26	0.40	1.00																	
F	-0.55	-0.23	0.27	-0.40	-1.00	1.00																
G	-0.31	0.31	0.38	0.07	-0.53	0.50	1.00															
H	-0.25	-0.10	-0.04	-0.40	0.19	-0.20	-0.15	1.00														
I	-0.45	0.53	0.87	-0.07	0.06	-0.06	0.27	-0.11	1.00													
J	-0.03	0.20	-0.02	0.04	0.04	-0.04	0.17	-0.16	0.11	1.00												
K	0.24	0.30	-0.17	0.34	0.63	-0.61	-0.47	0.48	-0.20	-0.41	1.00											
L	0.45	-0.17	-0.56	0.21	0.53	-0.50	-0.71	-0.17	-0.36	0.09	0.41	1.00										
M	0.16	0.10	-0.15	0.28	0.22	-0.19	-0.21	-0.36	-0.16	-0.24	0.45	0.61	1.00									
N	-0.24	-0.41	-0.19	-0.29	-0.41	0.43	-0.28	-0.38	-0.22	0.29	-0.40	0.44	0.14	1.00								
O	0.00	-0.34	-0.34	0.06	-0.17	0.18	-0.32	-0.52	-0.27	-0.03	-0.13	0.63	0.46	0.83	1.00							
P	0.17	-0.17	-0.53	0.08	0.22	-0.20	-0.47	-0.09	-0.51	0.51	0.17	0.66	0.35	0.52	0.40	1.00						
Q	-0.07	-0.23	0.01	-0.29	-0.40	0.36	0.55	0.16	-0.05	0.20	-0.61	-0.74	-0.79	-0.25	-0.52	-0.37	1.00					
R	-0.29	-0.14	0.19	-0.21	-0.73	0.70	0.73	0.06	-0.11	-0.34	-0.35	-0.78	-0.26	-0.27	-0.32	-0.55	0.63	1.00				
S	0.51	-0.37	-0.28	-0.16	0.23	-0.23	-0.33	-0.12	-0.20	-0.03	-0.19	0.04	-0.24	-0.10	-0.22	0.01	0.37	-0.07	1.00			
T	-0.07	0.54	0.67	0.14	0.33	-0.33	0.06	-0.16	0.89	0.11	-0.04	-0.11	-0.03	-0.32	-0.28	-0.42	-0.20	-0.33	-0.09	1.00		
U	-0.05	0.78	0.46	0.28	0.05	-0.05	0.42	0.28	0.31	0.33	0.15	-0.43	-0.31	-0.49	-0.68	-0.19	0.25	0.13	-0.13	0.25	1.00	
V	-0.15	0.51	0.57	0.04	-0.29	0.31	0.44	0.07	0.28	-0.18	0.12	-0.40	0.14	-0.41	-0.49	-0.43	0.02	0.44	-0.19	0.28	0.61	1.00

Note: A- Area(sqkm); B-Population (In Lakhs); C- Population Density(Persons/sqkm); D-PerCapita Income(Rs); E- Male%; F- Female%; G-City Buses(Nos); H- Road Safety Index; I- Road Density ; J- Registered Vehicles; K- Residential(%); L- Commercial(%); M- Industrial(%); N- Public & Semi Public; O- Recreational(%); P-Transport(%); Q- Agricultural(%); R- Water bodies(%); S- Open Spaces(%); T- Others(%); U- Trip Rate; V- Motorized Trip Rate

Annexure 1c: Correlation Matrix of CP3

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
A	1.00																					
B	0.85	1.00																				
C	-0.71	-0.49	1.00																			
D	0.89	0.69	-0.55	1.00																		
E	0.37	0.19	-0.38	0.44	1.00																	
F	-0.37	-0.19	0.38	-0.44	-1.00	1.00																
G	0.38	0.78	-0.18	0.27	-0.12	0.12	1.00															
H	0.56	0.32	-0.71	0.23	0.31	-0.31	-0.08	1.00														
I	-0.18	-0.03	-0.14	-0.13	-0.07	0.07	0.33	-0.25	1.00													
J	0.54	0.68	-0.20	0.68	0.19	-0.19	0.67	-0.30	0.41	1.00												
K	-0.11	0.01	-0.32	-0.05	0.48	-0.48	0.26	-0.03	0.69	0.22	1.00											
L	-0.19	-0.13	0.00	-0.13	-0.36	0.36	0.04	-0.38	-0.17	-0.05	-0.15	1.00										
M	-0.06	-0.11	0.06	0.13	0.19	-0.19	-0.19	0.00	-0.04	-0.13	0.25	-0.35	1.00									
N	-0.11	-0.08	-0.09	0.01	-0.33	0.33	0.12	-0.46	0.09	0.18	-0.03	0.94	-0.41	1.00								
O	0.26	0.50	-0.32	0.07	-0.19	0.19	0.58	-0.04	0.38	0.47	0.16	0.38	-0.51	0.45	1.00							
P	0.39	0.30	-0.60	0.50	0.00	0.00	0.36	0.08	0.48	0.44	0.41	0.05	0.22	0.27	0.08	1.00						
Q	-0.14	0.01	0.49	-0.40	-0.33	0.33	0.02	0.14	-0.41	-0.33	-0.60	-0.26	-0.36	-0.43	-0.07	-0.72	1.00					
R	0.91	0.62	-0.55	0.95	0.39	-0.39	0.09	0.39	-0.27	0.51	-0.26	-0.19	0.04	-0.08	0.01	0.35	-0.23	1.00				
S	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1.00			
T	-0.21	-0.55	0.19	0.01	0.36	-0.36	-0.78	0.06	-0.18	-0.37	-0.02	-0.49	0.63	-0.50	-0.80	-0.13	-0.15	0.10	--	1.00		
U	0.80	0.95	-0.32	0.64	-0.01	0.01	0.72	0.26	-0.21	0.59	-0.26	-0.07	-0.10	-0.07	0.43	0.19	0.18	0.61	--	-0.53	1.00	
V	0.67	0.87	-0.30	0.55	-0.28	0.28	0.80	0.06	0.02	0.66	-0.21	0.13	-0.18	0.19	0.59	0.36	0.05	0.48	--	-0.69	0.93	1.00

Note: A- Area(sqkm); B-Population (In Lakhs); C- Population Density(Persons/sqkm); D-PerCapita Income(Rs); E- Male%; F- Female%; G-City Buses(Nos); H- Road Safety Index; I- Road Density ; J- Registered Vehicles; K- Residential(%); L- Commercial(%); M- Industrial(%); N- Public & Semi Public; O- Recreational(%); P-Transport(%); Q- Agricultural(%); R- Water bodies(%); S- Open Spaces(%); T- Others(%); U- Trip Rate; V- Motorized Trip Rate

Annexure 1 d: Correlation Matrix of CA1

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
A	1.00																					
B	0.46	1.00																				
C	-0.02	0.85	1.00																			
D	0.27	0.84	0.80	1.00																		
E	-0.37	-0.18	-0.04	-0.22	1.00																	
F	0.40	0.24	0.10	0.27	-0.99	1.00																
G	0.29	0.50	0.45	0.45	-0.52	0.52	1.00															
H	0.46	0.54	0.22	0.14	0.00	0.00	0.19	1.00														
I	-0.80	-0.51	-0.15	-0.32	0.65	-0.64	-0.30	-0.45	1.00													
J	0.64	0.76	0.43	0.78	-0.19	0.23	0.45	0.35	-0.49	1.00												
K	-0.04	0.09	0.04	-0.26	0.27	-0.32	-0.42	0.56	-0.21	-0.18	1.00											
L	-0.53	-0.54	-0.31	-0.43	0.71	-0.68	-0.52	-0.51	0.86	-0.41	-0.13	1.00										
M	0.30	0.37	0.32	0.19	-0.29	0.36	-0.04	0.08	-0.47	0.10	0.13	-0.29	1.00									
N	0.33	-0.20	-0.35	0.06	-0.50	0.51	-0.27	-0.43	-0.36	0.10	-0.30	-0.11	0.27	1.00								
O	0.32	-0.19	-0.28	0.01	-0.25	0.29	-0.33	-0.46	-0.22	0.01	-0.35	0.07	0.37	0.81	1.00							
P	0.06	-0.40	-0.54	-0.28	-0.24	0.17	-0.42	-0.13	-0.25	-0.09	0.25	-0.11	0.02	0.60	0.16	1.00						
Q	0.47	0.39	0.15	0.29	-0.47	0.47	0.86	0.45	-0.32	0.49	-0.34	-0.49	-0.23	-0.21	-0.34	-0.28	1.00					
R	0.14	0.19	0.17	-0.03	-0.53	0.53	0.77	0.23	-0.20	0.03	-0.19	-0.37	0.01	-0.35	-0.27	-0.47	0.71	1.00				
S	-0.49	-0.41	-0.26	-0.19	0.05	-0.04	-0.27	-0.12	0.42	-0.46	-0.23	0.11	-0.17	-0.01	-0.04	0.03	-0.15	-0.14	1.00			
T	-0.61	-0.11	0.25	0.10	0.71	-0.67	-0.19	-0.45	0.74	-0.21	-0.25	0.61	-0.23	-0.40	-0.15	-0.46	-0.42	-0.34	0.27	1.00		
U	0.53	0.95	0.71	0.76	-0.26	0.32	0.57	0.66	-0.53	0.75	0.04	-0.61	0.24	-0.24	-0.26	-0.41	0.58	0.35	-0.28	-0.22	1.00	
V	0.12	0.74	0.79	0.52	-0.27	0.34	0.59	0.26	-0.28	0.33	0.00	-0.37	0.39	-0.35	-0.34	-0.51	0.33	0.54	-0.30	0.02	0.73	1.00

Note: A- Area(sqkm); B-Population (In Lakhs); C- Population Density(Persons/sqkm); D-PerCapita Income(Rs); E- Male%; F- Female%; G-City Buses(Nos); H- Road Safety Index; I- Road Density ; J- Registered Vehicles; K- Residential(%); L- Commercial(%); M- Industrial(%); N- Public & Semi Public; O- Recreational(%); P- Transport(%); Q- Agricultural(%); R- Water bodies(%); S- Open Spaces(%); T- Others(%); U- Trip Rate; V- Motorized Trip Rate

Annexure 1e: Correlation Matrix of CA2

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
A	1.00																					
B	0.16	1.00																				
C	-0.37	0.83	1.00																			
D	0.42	0.41	0.11	1.00																		
E	-0.47	-0.46	-0.19	0.01	1.00																	
F	0.47	0.45	0.18	-0.01	-1.00	1.00																
G	0.41	0.85	0.52	0.53	-0.57	0.57	1.00															
H	0.15	0.12	0.09	-0.05	0.34	-0.34	-0.15	1.00														
I	0.52	0.36	0.04	-0.01	-0.15	0.15	0.36	0.71	1.00													
J	0.33	0.88	0.63	0.33	-0.46	0.46	0.92	0.00	0.46	1.00												
K	0.51	-0.13	-0.31	0.45	0.40	-0.40	-0.14	0.60	0.32	-0.12	1.00											
L	0.37	0.28	0.01	0.41	-0.32	0.32	0.29	-0.36	-0.18	0.30	-0.06	1.00										
M	0.03	0.01	0.05	0.41	0.10	-0.10	-0.14	0.33	-0.13	-0.36	0.47	-0.26	1.00									
N	0.56	0.15	-0.21	0.36	-0.37	0.37	0.29	-0.37	-0.06	0.29	0.01	0.95	-0.37	1.00								
O	0.57	-0.15	-0.34	-0.18	-0.47	0.47	-0.09	-0.16	-0.03	0.01	0.16	0.51	-0.22	0.63	1.00							
P	0.89	0.03	-0.47	0.60	-0.25	0.25	0.34	0.17	0.44	0.13	0.60	0.16	0.30	0.33	0.23	1.00						
Q	-0.63	0.13	0.47	-0.60	-0.18	0.18	0.08	-0.37	-0.24	0.18	-0.76	-0.39	-0.40	-0.44	-0.23	-0.74	1.00					
R	-0.34	-0.62	-0.54	-0.36	0.16	-0.16	-0.37	-0.45	-0.28	-0.50	-0.52	-0.19	-0.34	-0.10	-0.27	-0.17	0.24	1.00				
S	-0.34	-0.63	-0.55	-0.38	0.17	-0.17	-0.37	-0.44	-0.27	-0.50	-0.51	-0.22	-0.35	-0.12	-0.27	-0.17	0.25	1.00	1.00			
T	-0.56	0.14	0.41	-0.06	0.52	-0.53	-0.21	0.63	0.20	-0.16	0.08	-0.54	0.43	-0.72	-0.77	-0.34	0.07	-0.08	-0.08	1.00		
U	0.11	0.96	0.87	0.35	-0.41	0.41	0.71	0.22	0.29	0.78	-0.04	0.27	0.14	0.10	-0.06	-0.04	0.09	-0.76	-0.78	0.20	1.00	
V	0.27	0.97	0.77	0.36	-0.52	0.51	0.77	0.22	0.41	0.82	-0.03	0.36	0.07	0.23	0.04	0.09	0.01	-0.73	-0.74	0.10	0.98	1.00

Note: A- Area(sqkm); B-Population (In Lakhs); C- Population Density(Persons/sqkm); D-PerCapita Income(Rs); E- Male%; F- Female%; G-City Buses(Nos); H- Road Safety Index; I- Road Density ; J- Registered Vehicles; K- Residential(%); L- Commercial(%); M- Industrial(%); N- Public & Semi Public; O- Recreational(%); P- Transport(%); Q- Agricultural(%); R- Water bodies(%); S- Open Spaces(%); T- Others(%); U- Trip Rate; V- Motorized Trip Rate

Annexure 1f: Correlation Matrix of CA3

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
A	1.00																					
B	0.21	1.00																				
C	-0.34	0.81	1.00																			
D	0.85	0.38	-0.07	1.00																		
E	0.78	0.51	0.13	0.93	1.00																	
F	-0.78	-0.51	-0.13	-0.93	-1.00	1.00																
G	-0.20	0.89	0.99	0.06	0.27	-0.27	1.00															
H	0.12	0.57	0.30	0.00	-0.12	0.12	0.32	1.00														
I	-0.33	0.60	0.85	0.00	0.28	-0.28	0.85	-0.17	1.00													
J	0.23	0.78	0.65	0.50	0.71	-0.71	0.75	0.03	0.80	1.00												
K	-0.41	-0.33	0.00	0.02	-0.05	0.05	-0.08	-0.60	0.20	-0.05	1.00											
L	-0.84	-0.55	-0.02	-0.74	-0.79	0.79	-0.19	-0.28	-0.07	-0.62	0.58	1.00										
M	0.42	0.32	0.18	0.81	0.80	-0.80	0.25	-0.32	0.33	0.54	0.53	-0.31	1.00									
N	-0.35	-0.01	0.16	-0.23	-0.05	0.05	0.17	-0.33	0.53	0.46	0.11	-0.07	-0.12	1.00								
O	-0.40	0.63	0.87	0.07	0.18	-0.18	0.84	0.06	0.81	0.61	0.46	0.15	0.48	0.17	1.00							
P	0.70	0.43	0.06	0.83	0.93	-0.93	0.21	-0.18	0.33	0.78	-0.09	-0.84	0.66	0.29	0.10	1.00						
Q	-0.27	-0.15	-0.03	-0.68	-0.65	0.65	-0.10	0.39	-0.33	-0.58	-0.59	0.31	-0.84	-0.33	-0.39	-0.72	1.00					
R	0.84	0.55	-0.02	0.77	0.75	-0.75	0.14	0.41	-0.04	0.56	-0.54	-0.97	0.32	0.00	-0.14	0.79	-0.34	1.00				
S	0.08	-0.48	-0.43	-0.34	-0.17	0.17	-0.42	-0.41	-0.20	-0.30	-0.42	-0.02	-0.50	0.16	-0.68	-0.07	0.49	-0.14	1.00			
T	0.84	0.05	-0.52	0.71	0.56	-0.56	-0.38	0.18	-0.44	0.17	-0.34	-0.78	0.24	-0.02	-0.49	0.66	-0.39	0.85	-0.02	1.00		
U	0.23	0.99	0.79	0.39	0.49	-0.49	0.86	0.62	0.54	0.72	-0.33	-0.52	0.32	-0.11	0.62	0.38	-0.12	0.54	-0.53	0.05	1.00	
V	0.09	0.98	0.84	0.30	0.40	-0.40	0.90	0.62	0.61	0.75	-0.27	-0.46	0.27	0.04	0.68	0.34	-0.15	0.48	-0.58	0.00	0.98	1.00

Note: A- Area(sqkm); B-Population (In Lakhs); C- Population Density(Persons/sqkm); D-PerCapita Income(Rs); E- Male%; F- Female%; G-City Buses(Nos); H- Road Safety Index; I- Road Density ; J- Registered Vehicles; K- Residential(%); L- Commercial(%); M- Industrial(%); N- Public & Semi Public; O- Recreational(%); P- Transport(%); Q- Agricultural(%); R- Water bodies(%); S- Open Spaces(%); T- Others(%); U- Trip Rate; V- Motorized Trip Rate