DEVELOPMENT OF A GIS BASED TRANSPORT DEMAND ESTIMATION MODEL THAT INTEGRATES LAND USE AND TRANSPORTATION INFRASTRUCTURE DEVELOPMENT SCENARIOS

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University of Moratuwa
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Thesis submitted in total fulfillment of the requirements for the degree of Doctor of Philosophy

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Sri Lanka

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DECLARATION

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ABSTRACT

Transportation issues are becoming severe day by day in Sri Lanka. Ignoring the importance of integrating transport and land use properly in the travel demand estimation process, due to its vast complexity and not having a proper mechanism to understand it easily, is the main reason for those issues. Identifying that, this research developed a GIS based transport and land use model that helps relevant authorities to easily understand and incorporate the complex interaction to the travel demand estimation process, as the first attempt in Sri Lanka until now. The model has two sub models called macro and micro models that separately look after the regional level and local level travel demand estimations respectively, although final results at any level combine both models' outputs.

The macro model has been developed for whole Sri Lanka taking the Divisional Secretariat (DS) divisions as Traffic Analyzing Zones (TAZs). Algorithms calibrated by the linear regression analyzing technique incorporating the Origin-Destination (OD) matrix data and socio-economic data are the main modeling technique for the macro model. Optimum counting locations derived through a new approach named as the "top-down approach" for OD surveys enhanced the accuracy of the OD matrix and thereby increasing the accuracy at all stages. As a prototype, a micro model was built for the Colombo DS division. The study area of the micro model can be any geographic area according to data and time availability. The activity based approach in the microsimulation modeling technique was used to develop the micro model, which uses household and railway passenger OD surveys, for calibration. Finally, a GIS based computer program was developed to improve the effectiveness and user-friendliness of these models.

Keywords: *transportation, land use, integration, modeling*

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LIST OF ABBREVIATIONS

ALS	Area Licensing Scheme
CA	Cellular Automata
CAST	City Analysis Simulation Tool
CBD	Central Business District
CDSD	Colombo Divisional Secretariat Division
CL	Counting Location
CLP	Constraint Logic Programming
CMR	Colombo Metropolitan Region
DRAM	Disaggregated Residential Allocation Model
DS	District Secretariat
DSD	District Secretariat Division
EMDA	East Midlands Development Agency
EMPAL	Employment Allocation Model
EMRA	East Midlands Regional Assembly
ERP	Electronic Road Pricing
ESRI	Environmental Systems Research Institute
GA	Genetic Algorithm
GIS	Geographic Information Systems
GN	Grama Niladhari
GOEM	Government Office of the East Midlands
GPS	Global Positioning Systems
ILUMASS	Integrated Land Use Modeling and Transportation System Simulation
ITLUP	Integrated Land Use Transportation Package
LA	Local Authorities

MCC	Manual Classified Counts
MPRE	Maximal Possible Relative Error
NOO	Number of Occurrences
NPPD	National Physical Planning Department
OCL	Optimum Counting Locations
OD	Origin Destination
PCL	Possible Counting Locations
POLIS	Projective Optimization Land Use Information System
RDA	Road Development Authority
RPTA	Regional Public Transportation Authority
RS	Remote Sensing
SPARTACUS...	System for Planning and Research in Towns and Cities for Urban Sustainability
TAZ	Traffic Analysis Zone
TUS	TRANUS User Cell
UDA	Urban Development Authority
USA	United States of America
UK	United Kingdom
VB	Visual Basic
VMT	Vehicle Miles Travelled
VQS	Vehicle Quota System

CHAPTER 01: INTRODUCTION

1.1 Background

Global warming, congestion, price of non-renewable resources such as oil, urban fabric disruption and increasing levels of psychological stress are some of the burning issues in the contemporary world. It can be observed that ineffectiveness of transportation systems contributes at some level to all the above mentioned issues. It can be seen that one of the key factors that leads to ineffective transportation is lack of integration between transportation planning and land-use planning.

It is well understood that transportation has a significant impact on land use and vice versa (Rodríguez etl, 2003: Lemp etl: Litman, 2008: Waddell: Memon and Douglass, etc.) Current and future land use plays an important role in transportation planning, while transportation is a key factor in determining the land usage in a given area. In addition, transportation improvements alter accessibility of land, and thereby their potential for development and redevelopment (Kaiser et al, 1995). Similarly, planning for new public transport services (new and existing infrastructure) should be closely aligned with land use planning, corridor development and new developments (Department of Urban Affairs and Planning, New South Wales et al, 2001). Another key issue is that a significant portion of land is used for providing transportation infrastructure. In most of the cities one third of all the land is devoted to streets, rail road yards, terminals, airports, and parking facilities (Owen, 1972). Furthermore, traffic congestion (inadequacy of transportation infrastructure) is an initial indication of ad hoc development. Concept of integrating land use and transportation should ideally be considered at the policy level. Transportation policies must consider the spatial strategy and conversely the transport strategies must be taken into account during land use planning (Cullingworth and Nadin, 2006).

Despite knowing the importance of integrating land use and transportation in development plans, current evidence from many cities around the world (high level of congestion, excessive levels of carbon pollution, etc.) show that many planners still fail to take them into consideration. This can be due to ignoring these interactions or failing to understand how to integrate them properly into the planning process (Kaiser et al, 1995). Although, the Colombo Metropolitan Regional (CMR) Plan correctly identified that “incompatible land use and ribbon development along the principal trunk roads in the region has led to traffic congestion and delay in passenger travel”, they were unable to characterize this interaction – a western perception – from a local standpoint (Perera, 2007). Hence, the proper integration of land use and transportation was not a key consideration at the time of preparing the CMR Plan. Although the marriage between land use and transportation is a natural one, it has traditionally been underserved in planning curricula (Krizek and Levinson). Furthermore, integration of land use and transportation is not a component in the planning education. Hampering coordination is the reality that the benefits of careful transport-land use integration are often not evident until ten or more years in the future (Cervero). Dr. Carlo Sessa says, “We wanted to look at ways of tackling existing problems of mobility in urban environments using innovative transport policies, but also blending in other important aspects, such as land uses which have an impact on transport”. Robert Cervero states that, he found smart growth to be a nice short hand for transport and land use integration. From above evidence, it can be concluded that further research is required to understand and model the complex nature of integrated transport-land use in a way that can be easily incorporated into the town planning process.

Numerous solutions have been proposed for integrating transportation and land use for better urban environments. The most profound solution is to model these interactions and DRAM/ EMPAL, ITLUP, URBANSIM, MEPLAN and TRANUS are some examples of such models. Road Development Authority (RDA) of Sri Lanka, which is the official authority for planning the transportation sector mostly, presently uses the STRADA and HDM models for the decision making process.

1.2 Need for Further Research of Transport and Land Use Models

Available literatures argue that these models have failed to fully capture the effects of the unprecedented levels of development in current urban areas taking the prevailing issues in current urban environments throughout the world. Remarkably, it can be seen that most of the models have neglected the social aspect in details and changing preferences of living beings as well. Further, most models were developed based on a particular city undertaking particular city’s travel behavior and the development pattern; therefore, there is an extreme doubtful situation that how much accuracy will be there in applying to other cities even in the same nature. While the developed countries have been using models to effective integrating the transport and land use, it does not seem that developing countries such as Sri Lanka effectively utilize this technique. It is doubtful whether models developed for the developed countries can be applied for developing countries where the travel pattern is totally different with the different land uses, transportation infrastructures, distance between cities, and people’s attitudes, preferences and necessities.

Not only the transport and land use models, even the concept of integrating transport and land use was a distant factor till recently in Sri Lanka. Few occasions can be seen where transport models were in use but there is no evidence for transport and land use models at all. Most of the transport models were transport demand models and, these models have been project specific and have limited use in national levels of transport planning. Hence, the need of transport and land use models that are capable of utilizing in all decision making levels in Sri Lanka has been a timely need for a longer time. TRANSPLAN developed by the University of Moratuwa of Sri Lanka can be seen as the initial step in developing a transport and land use model for Sri Lanka. TRANSPLAN has two major traffic distribution models and several auxiliary models produced on the basis of real situations of the country. Having determined the characteristics and desired capability of such ultimate planning tool, developers of TRANSPLAN perceive TRANSPLAN as its first phase while provision being allowed for incorporation of subsequent improvements.

Hence, developments of more accurate and broad transport and land use models are essential for incorporating integrated transport-land use decisions into town planning process in the future for Sri Lanka with the lessons learnt from TRANSPLAN and other transport and land use models, which are in operation all over the world. There is a significant difference in the travel behavior between regional and local levels in Sri Lanka and further, decisions need to be taken and the information needed for decision makings are very different in micro level comparing to the macro level. Therefore, two models are required to address the micro and macro levels.

1.3 Research Objectives

1) To characterize the complex interactions between transport and land use based on existing theories and case studies.
2) To develop macro level traffic demand estimation model incorporating the effects of land uses and its changes in addition to the parameters used in TRANSPLAN Model.
3) To enhance the above model to assign estimated traffic flows to the road networks at micro level based on land use pattern using GIS tools.

1.4 Scope

This research works on producing two levels of traffic demand estimating models, which effectively incorporate the effects of land uses. Those two levels are macro and micro levels. The macro level model covers entire Sri Lanka and the micro model was prepared for the District Secretariat division level and here, the Colombo DS division was taken as the case study. But it can be used as an ideal framework for the preparation of micro models for other DS divisions with minor changes.

1.5 Research Questions

1. <u>To assess current trends of travel demand estimation</u>

- Comparative study of new trends of travel demand estimation
- Importance of integrating effects of land uses to travel demand estimation process
- Types of travel demand estimation models

2. <u>To describe the current transport system and identify travel behavior of the people in the study area</u>

- To understand the macro level travel behavior of the study area
- To understand the micro level travel behavior of the study area

- How the travel behavior of people varies as per their socio-economic background
- To analyze the decision makers' requirements and capabilities, and their working environments

3. To study the structure of present day transport and land use models
    - How present models were made of? (Input parameters, output parameters, modeling structure, spatial techniques and user interfaces)
    - Prospects and constraints

4. To select appropriate transport and land use modeling technique to simulate the travel pattern in Sri Lanka
    - To select input parameters
    - To select output parameters
    - To select the modeling structure
    - To select appropriate spatial techniques
    - To select appropriate user interfaces

5. To develop macro model
    - To use the Top-Down approach for selecting counting locations for OD surveys
    - To prepare an accurate OD matrix
    - To carry out the model calibration with socio-economic data
    - To develop algorithms
    - To carry out the model validation
    - To use the GIS to develop the interfaces

6. To select appropriate transport and land use modeling technique to simulate the travel pattern in Colombo DS Division
    - To select input parameters
    - To select output parameters
    - To select the modeling structure
    - To select appropriate spatial techniques

- To select appropriate user interfaces

7. To develop micro model
   - To carry out household and railway passenger OD surveys
   - To prepare a node-based OD matrix
   - To develop algorithms
   - To carry out the model validation
   - To use the GIS to develop the interfaces

1.6 Conceptual Framework

The framework is designed to be carried out in three phases namely the pre-analysis stage (Phase 1), analysis stage (Phase 2) and finally the technical stage (Phase 3). Pre-analysis stage provides a profound background in several aspects: the travel behavior of study areas and how changes are occurring, facets of traffic demand estimation, the knowledge of working environments of transport related authorities and their requirements, and structures of present day transport and land use models along with prospects and constraints of them. The knowledge gathered from the pre-analysis stage provides a fine setting for the selection of appropriate modeling approaches for both macro level and micro level travel demand estimations in association with land uses. Other than that analysis stage comes up with what are the respective input parameters, output parameters, modeling structures, spatial techniques and user interfaces for the two approaches. Further, designing data collection methods, data collection and developing algorithms will also occur in the analysis stage. Finally, technical stage deals with the software development of the proposed models using the GIS.

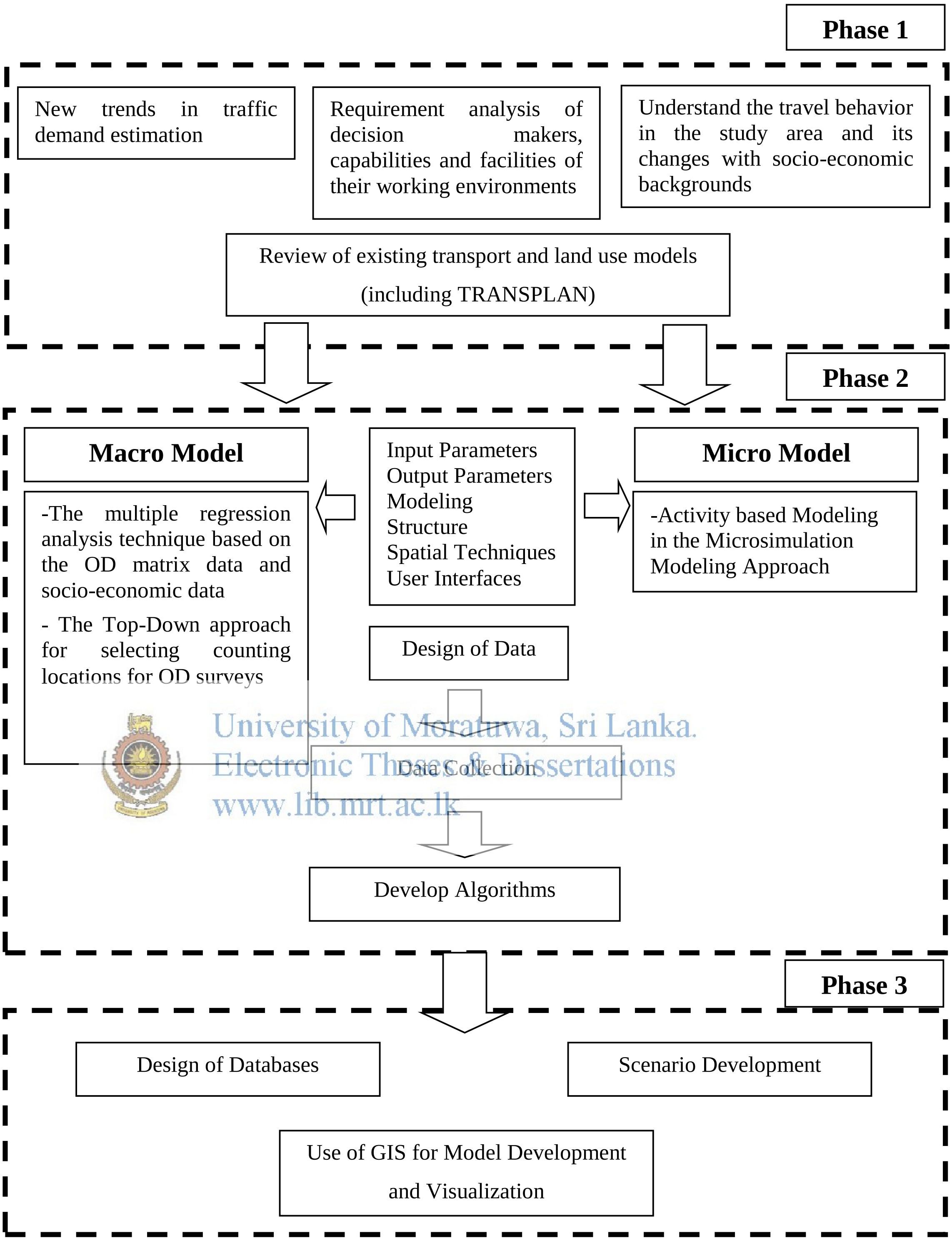


Figure 1.1: Conceptual Framework

1.7 Research Design

The research is designed to be carried out in several phases.

1.7.1 Identification of Present Trends

The study starts with the general overview of the current scenario of transport systems in the study areas, traffic demand estimation aspects and current environments of the transport related authorities. At next, a deep analysis of several transport and land use models including the TRANSPLAN, which are in operation presently, will be carried in the means of input parameters, output parameters, modeling structures, spatial techniques and user interfaces. Basis of this phase will be made from the available literature, interviews and observations made during the field visits. This phase forms the basis for formulating the problem and developing the methods for analysis and data requirements.

1.7.2 Formation of Two Scenarios

In transport planning, fundamentally two major approaches can be seen: namely regional (macro-level) and local (micro-level) planning. The different nature of the macro-level and micro-level travel behavior is well acknowledged in the literature. Therefore, to make informed transportation planning decisions on one level, decision makers have to be able to predict travel characteristics and usage of transport services under different socio-economic scenarios, transport services and land use configurations comparing to other level travel demand estimations. Hence, separate models are required to address the macro-level and micro level.

1.7.2.1 Scenario 1: Macro Level Model Development

Whole Sri Lanka was taken as the study area. DS divisions were taken as Traffic Analysis Zones (TAZs) where number of TAZs is 331. Only A and B class roads were taken as prospective routes assuming that at the macro-level, awareness about the local roads (C, D and minor roads) is very low. Most suitable modeling approach and relevant input parameters, output parameters, modeling structures, spatial techniques and user interfaces for the macro-level analysis were selected by analyzing the information gathered in early phases. Data collection was carried out at next, but in advance a detailed design of data collection methods was done with the help of available literature, reports, available data and professional experiences. Algorithms were developed in where necessary following to the data collection. Finally GIS and customized GIS applications were used for the appropriate visualization of outputs and map production for each theme.

1.7.2.2 Scenario 2: Micro Level Model Development

The micro model was designed to the DS division level. The micro model gets the idea of inter trips from the macro model and itself handle all means of intra trips. Here, all road types (A, B, C, D, E and minor roads) were undertaken for the analysis part. Same as the scenario 1, most suitable modeling approach and relevant input parameters, output parameters, modeling structures, spatial techniques and user interfaces for the macro-level analysis were selected by analyzing the information gathered in early phases. At next, designing the data collection methods and data collection was done. Algorithms were developed where necessary in here as well and the GIS handles the visualization part and map productions. The Colombo DS division was selected at this point for the demonstration of the micro level model development.

1.7.3 Model Development

The transport modeling was done for both scenarios.

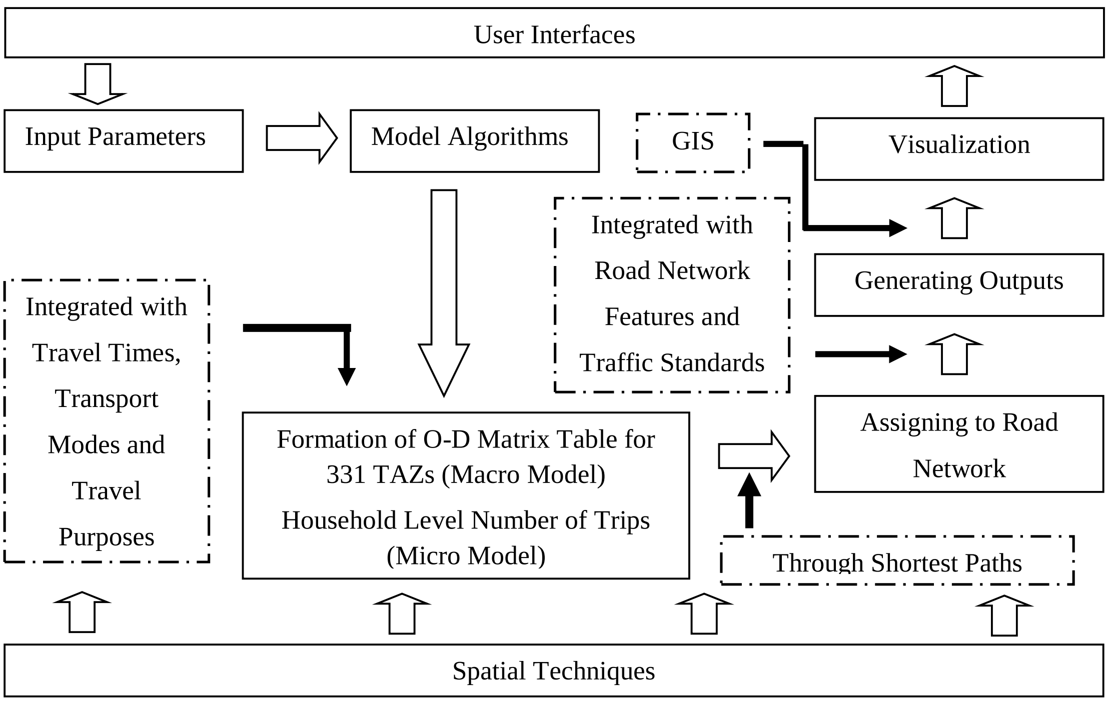


Figure 1.2: Modeling Framework

1.8 Thesis Structure

The thesis comprises of seven chapters as per following sequence:
Chapter one is the Introduction chapter. This chapter includes the background of the research, research problem, research objectives and questions, and research design. In this chapter it is clearly explained the need and the rational for this research. Further it discusses about the primary idea of the research design and the data/ information required for this research. The conceptual framework is also discussed in this chapter.

Chapter 2 discusses the literature primarily relevant to the travel demand estimation. Review of the importance of modeling for better travel demand estimation, different types of travel demand models such as trip based models and activity based models has been carried out. Then, discussions are mentioned related to the transport and land use models more deeply. Finally, a deep analysis following a comparison study of 11 widely used transport and land use throughout the world has been documented.

Chapter 3 initially discusses about the transport and land use aspects and responsible agencies for them in Sri Lanka. Modeling techniques, input parameters, output parameters, spatial techniques and user interfaces derived from models reviewed in Chapter 2 are further looked on. Then, a literature review has been carried out to oversee the future prospects of above parameters. The profound analysis carried out to select the model parameters for both macro and micro models has been documented in the latter stage of the Chapter 3.

Chapter 4 starts by presenting the current problems in carrying out the roadside interview O-D surveys and current approaches for solving those problems. A new approach, called Top-Down Approach, that eliminates both double counting and leaky screen-line problems is presented then. A detailed description of regression analysis carried out between O-D matrix outputs and socio-economic data has also included in this chapter. Final stage of the chapter includes the description of algorism developed for the macro level analysis.

Chapter 5 starts with explaining the micro modeling approach undertaken and the study area. The preparation of O-D matrix for the study area is explained then. Chapter also includes the description of the traffic assignment methods involved. A detailed conclusion has been put to the final stage of the chapter describing the overall process involved.

Chapter 6 describes about the software architecture and functions of the software program.

Chapter 7 is named as the ‘Conclusion and Critical Evaluation”. Early stage gives the overall conclusion to the importance of integrating the land use aspect for transport decisions, modeling techniques and also to the overall modeling approach. Then, writer has critically argued the overall process comparing other existing other processes and, the limitations and mistaken occurred throughout the process.

CHAPTER 02: LITERATURE REVIEW

2.1 Travel Demand Estimation

2.1.1 Introduction

Transport planning is an extensive undertaking. The basic purpose of transportation planning and management is to match transportation supply with travel demand, which represents ‘need’. A thorough understanding of existing travel pattern is necessary for identifying and analyzing existing traffic related problems. Therefore, transportation planning process heavily relies on travel demand forecasting, which involves in predicting the impacts that various policies and programs have on travel in both urban and rural areas. The demand for transportation is created from the general growth of a community, major developments and other activities like recreation and tourism. The supply of transportation system is represented by the planned road network, intersections’ performance, and roadway capacities. The forecasting process provides detailed information on traffic volumes, bus patronage, turning movements, which are to be used by engineers and planners in their designs. Further, the total magnitude of travel demand alone is not sufficient for detailed planning and management purposes. The spatial and temporal distributions of travel also are important items of information to be considered in determining supply strategies. In addition to the spatial and temporal characteristics of travel demand, there are several other aspects of travel demand which must be recognized. ‘Trip purposes’ such as work, shopping, and social-recreation; and trip maker’s characteristics such as income and car ownership, are important factors influencing the elasticity of demand reflecting its sensitivity with respect to travel time and cost.

The travel forecasting as a formal process began in the 1950s; an era when the interstate highway system was first being built and post-war prosperity was making better housing and auto travel more widely affordable (Barnes & Davis, 1999). Thereafter, there is no other process, other than the traffic demand estimation process, which has been and is being undergone with many developments over last six decades.

2.1.2 Methods for Traffic Demand Estimation

Diverse traffic demand estimation methods can be put into two basic categories namely the direct estimation of traffic volume by trend analysis and the stepwise procedure. Both categories are with their own advantages and disadvantages.

2.1.2.1 Direct Estimation of Traffic Volume by Trend Analysis

If traffic volume data are available for a road segment or a transit line of interest for several years in the past, the historical trend can be identified and extrapolated to estimate future volumes. This approach can be more appropriately applied for short range forecasts. Trend based forecasts are appropriate also for aggregate values such as total VMT or transit rides in an urban area. However, major changes in the land development pattern and transportation network can cause substantial changes in the travel pattern, and if such changes are likely then trend exploration would not be appropriate. Therefore, for long range forecasts of traffic volumes on individual segments of a road network or the number of passenger trips on individual transit routes, the trend analysis is not used.

2.1.2.2 Stepwise Procedure

A widely used travel estimation procedure for long-range forecasts of traffic volumes on a highway network uses several steps in a sequence (see Figure 2.1). Each step here requires a particular type of model or procedure, and there are different choices of models at each step. One of the major advantages of this procedure is its ability to reflect several types of changes, which may occur in the future: a) changes in trip making rates, b) changes in development pattern resulting in altered travel pattern, c) changes in transportation mode usage, and d) changes in transportation network. Another advantage of the stepwise, or sequential, procedure is that it generates several types of useful information at the end of various steps. The disadvantage of the procedure is that it needs a large amount of data for model or method development, which sometimes may need the support of specially designed software packages. The stepwise procedure is popularly known as the four step modeling process as this procedure includes four major steps: trip generation, trip distribution, mode choice, and traffic assignment. Additionally network analysis must be done to develop a few types of information that are needed for the other steps.

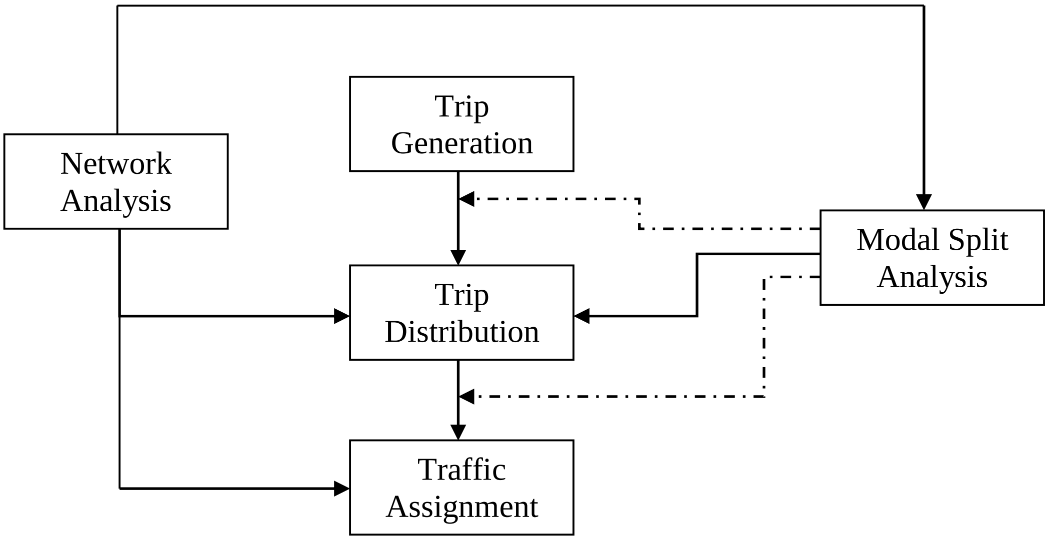


Figure 2.1: Stepwise/ Sequential Procedure

2.1.3 New Trends in Traffic Demand Estimation

The travel demand estimation process, particularly the four-step modeling process, has seen a number of enhancements. These include the more widespread incorporation of time-of-day modeling into what had been a process for modeling entire average weekdays, common use of supplementary model steps, such as vehicle availability models, and the inclusion of non-motorized travel in models; and enhancements to procedures for the four main model components (e.g., the use of logit destination choice models for trip distribution). Further, data collection techniques have advanced, particularly in the use of new technology such as Global Positioning Systems (GPS) as well as improvements to procedures for performing household travel and transit rider surveys and traffic counts. A new generation of travel demand modeling software has been developed, which not takes only advantage of modern computing environments but also includes, to various degrees, an integration with Geographic Information Systems (GIS). Moreover, there has been an increased use of integrated transport and land use models in contrast to the use of static land use allocation models. The tour-based and activity-based modeling has been introduced and implemented.

Increasingly, travel demand models have been more directly integrated with traffic simulation models. Most travel demand modeling software vendors have developed traffic simulation packages.

2.2 Importance of Integrating Transportation and Land Use for the Travel Demand Estimation Process

Land use patterns affect accessibility, people's ability to reach desired services and activities that affects mobility, the amount and type of travel activity (Litman, 2003). Urban areas have more accessible land use and more diverse transport systems, but slower and more costly automobile travel. Suburban and rural areas have less accessible land use and fewer travel options but driving is faster and cheaper per mile. Numerous studies have identified the effects of various land use factors on travel activity (Barla, Miranda-Moreno and Lee-Gosselin, 2010; CARB, 2010 and 2011; Ewing, et al., 2007; Ewing and Cervero, 2010; Guo and Gandavarapu, 2010; Kuzmyak and Pratt, 2003; Kuzmyak, 2012; TRB, 2005; ULI, 2010).

It is also well understood that transportation has a significant impact on land use and vice versa (Rodriguez etl, 2003; Lempetk Litman, 2008; Waddell; Memon and Douglass, etc.). Major argument is, transportation improvements alter the accessibility of land, and thereby their potential for development and redevelopment (Kaiser et al, 1995). Robert Cervero states that, "I find smart growth to be a nice short hand for transport and land use integration". Despite knowing the importance of integrating land use and transportation in development plans, current evidences from many cities around the world (high level of congestion, excessive level of carbon pollution, etc.) show that many planning related professionals still fails to take them into account. Although the marriage between land use and transportation is a natural one, it has traditionally underserved in planning curricula (Krizek and Levinson). This can be due to ignoring these interactions or failing to understand how to integrate them properly into the planning process (Kaiser et al, 1995).

By all these, it can be concluded that travel demand estimations will not be correct if effects of land use changes are not taken into account over the estimated period.

Therefore, there is a huge obligation to properly integrate the transport and land use for the travel demand estimation process by correct means.

2.3 Travel Demand Models

Most of the time, the travel demand estimation process comes in a model form as it occupies with lots of mathematical calculations, deals with lots of parameters and needs to generate many outputs.

2.3.1 Modeling

2.3.1.1 Introduction

Modeling, familiar to almost each and every professional aspects, is about building representations of things in the ‘real world’ and allowing ideas to be investigated. A model is an abstraction, which allows concentrating on the essentials of a (complex) problem by keeping out non-essential details. In general all models have an information input, an information processor, and an output of expected results. Other than that, several key features in common with the development of any model can be seen; simplifying assumptions must be made, boundary conditions or initial conditions must be identified, the range of applicability of the model should be understood. The main use of modeling is, aid to decision making process while main advantage of modeling is, where it was made out of lots of human resources, professional inputs, money, time, equipments, can repeatedly be used after with no or least of above. Another use is that, modeling is used in occasions where man wanted to go beyond his brain’s limited imagination and computing power. One such occasion is the predicting future behavior or performing virtual experiments, or to make decisions about courses of action based on the likelihood of expected outcomes by better understanding the historical data.

2.3.1.2 Modeling in Transport Sector

Transport sector should be well managed because of many reasons such as resources are scare and there is a severe need to be justified against current objectives and uncertainties, major transport improvements have long planning periods, long lives and long pay back periods, transport systems consists of many complex interactions and changes, etc. In such situation, models can do a great job by undertaking complex calculations to simplify appraisals, providing information to aid understanding, enabling consistent comparisons of a large range of options, enabling appraisal against objectives and uncertainty, etc. Transport sector, where over the last forty years a variety of operational models has been developed and applied, is presently also undergone with vast number of modeling. But it still senses for more developments profoundly. Different types of models are in progress in transport sector throughout the world; few of among them are travel demand models, economic evaluation models, integrated transportation and land use models, simulation models, price elasticity models, etc. These types of models have seen significant improvements over the years and have become a principal tool for strategic transportation planning now. But, common issues can be seen in more or less with each and every transportation models. Some of the burning issues can be identified of these transportation models; the assumptions and analysis methods used in these models can affect the planning decisions, conventional models primarily measure motor vehicle travel rather than accessibility, and they tend to undervalue alternative modes and alternative ways of improving accessibility, such as smart growth concepts, especially like the integration with land uses (Loudon and Parker, 2008).

Moreover, travel models tend to focus on quantitative factors like travel speed, operating cost and crash rates and undervalue qualitative factors such as travel convenience, comfort and security (Litman, 2007). Further, travel surveys, one of the main inputs for models, often undercounts short trips, non-motorized travel, off-peak travel, etc. Nearly every one of transportation professionals has argued that most current models only measure a few impacts.

2.3.2 Types of Travel Demand Models

While the travel demands estimation is one of the outputs in all transportation models, and 90% of them the travel demand estimation is the major output. Therefore, transport models can also be identified as travel demand models. Preliminary, travel demand models can be seen in two aspects. Those are trip-based models and activity-based models.

2.3.2.1 Trip-Based Models

2.3.2.1.1 Aggregate Models

The earliest travel demand models were simple mathematical models, such as a gravity model or an entropy model that quantified travel as a function of the size of a zone. These were essentially aggregate level trip-based models. The number of trips generated from a zone was considered to be proportional to the population in the zone, while the number of trips attracted to a zone was considered to be proportional to the number of sources of attraction in the zone. Moreover, the travel between zones was considered to be inversely proportional to the distance between the zones.

2.3.2.1.2 Disaggregate Models

Advances in modeling techniques resulted in a shift away from these aggregate models and led to the development of disaggregate trip-based models. These models use disaggregate level data on the trips made by individuals between the zones in the study area, and apply modeling methodologies such as constrained optimization and random utility maximization. The fundamental difference between aggregate and disaggregate models is that the disaggregate models view the individual (or household or firm) as the decision-making unit. In other words, the disaggregate models take into account the effects of individual socio-demographics (or firm characteristics) on travel-related choices. However, in practice, due to the data limitations and modeling constraints, disaggregate trip-based models are occasionally implemented in an aggregate manner with aggregate zonal socio-demographic data.

2.3.2.1.3 Four-Step Modeling Process

The history of demand modeling for transportation related studies has been dominated by the modeling approach that has come to be referred to as the four step model (McNally, 2007). The first comprehensive application of the four-step model system was in the Chicago Area Transportation Study with the model sandwiched by land use projection and economic evaluation (Weiner, 1997). There are four components commonly included in the four step process, namely trip generation, trip distribution, mode choice and assignment. The serial nature of the process is not meant to imply that the decisions made by travelers are actually made sequentially rather than simultaneously, nor that the decisions are made in exactly the order implied by the four-step process.

2.3.2.1.3.1 Trip Generation

Trip generation is to estimate number of trips of each type that begin or end in each location, based on the amount of activity in an analysis area. In most models, trips are aggregated to a specific unit of geography, which is mostly called a Traffic Analysis Zone (TAZ). The estimated number of daily trips will be in the flow unit that is used by the model, which is usually one of the followings: vehicle trips, person trips by all modes, several modes or one mode. Trip generation models require some explanatory variables that are related to trip making behavior and some functions that estimate the number of trips based on these explanatory variables. Typical variables include the number of households classified by characteristics such as number of persons, number of workers, vehicle availability, income level, and employment by type. The output of trip generation is trip productions and attractions by traffic analysis zone and by purpose.

Trip generation can reflect time of day with productions and attractions being generated for specific time periods; this is often the case when complied land use trip rates are utilized since these rates are typically defined by time of day. Adjustments for time of day, however, are more common after subsequent four step modeling steps.

2.3.2.1.3.2 Trip Distribution

This addresses the question of how many trips travel between units of geography. In effects, it links the trip productions and attractions from the trip generation step. Trip distribution requires explanatory variables that are related to the cost and time of travel between zones, as well as the amount of trip-making activity in both the origin zone and the destination zone. The outputs of trip distribution are production-attraction zonal trip tables by purpose.

2.3.2.1.3.3 Mode Choice

Mode choice is the third step in the four-step process. In this step, the trips in the tables output by the trip distribution step are split into trips by travel mode. The mode definitions vary depending on the types of transportation options offered in the model's geographic region and the types of planning analyses required. The mode definitions can be generally grouped into automobile, transit, and non-motorized modes. Transit modes may be defined by access mode (walk, auto) and by service type (local bus, express bus, heavy rail, light rail, commuter rail, etc.). Non-motorized modes, which are not yet included in some models, especially in small urban areas, include walking and bicycling. Auto modes are often defined by occupancy levels (drive alone, shared ride with two occupants, etc.). The outputs of the mode choice process include person trip tables by mode and purpose and auto vehicle trip tables.

2.3.2.1.3.4 Assignment

The final step in the four-step process is the trip assignment. This step consists of separate highway and transit assignment process. The highway assignment process routes vehicle trips from the origin-destination trip tables onto paths along the highway network, resulting in traffic volumes on network links by the time of the day and, perhaps, vehicle type. Speed and travel time estimates, which reflect the levels of congestion indicated by link volumes, are also output. The transit assignment process routes trips from the transit trip tables onto individual transit routes and links, resulting in transit line volumes and stations.

2.3.2.2 Activity Based Modeling Process

One of the most fundamental and oft-quoted principles is that travel demand is derived from activity demand (Jones, 1979). This principle implies a decision framework in which travel decisions are components of a broader activity scheduling decision, and calls for modeling activity demand. The activity-based approach to travel demand analysis views travel as a derived demand; derived from the need to pursue activities distributed in space (Axhausen and Garling, 1992). The approach adopts a holistic framework that recognizes the complex interactions in activity and travel behavior. The conceptual appeal of this approach originates from the realization that the need and desire to participate in activities is more basic than the travel that some of these participations may entail. In order to accurately quantify the travel needs of the population, it is therefore important to model the activity-travel patterns of the population (the activity-travel pattern of an individual is defined as a complete string of activities undertaken by the person over the course of a day characterized by location, time of day, and mode of travel between locations).

2.3.2.3 Trip-Based Models vs. Activity-Based Models

The fundamental difference between the trip-based and activity-based approaches is that the former approach directly focuses on "trips" without explicit recognition of the motivation or reason for the trips and travel. The activity-based approach, on the other hand, views travel as a demand derived from the need to pursue activities (Jones *et al.*, 1990; Bhat and Koppelman, 1999; and Davidson *et al.*, 2007), and focuses on "activity participation behavior".

Another difference between the two approaches is in the way the travel is represented. The trip-based approach represents the travel as a mere collection of "trips". Each trip is considered an independent of other trips, without considering the inter-relationship in the choice attributes (such as time, destination, and mode) of different trips. Such a neglect of the temporal, spatial and modal linkages between the trips can lead to illogical trip chain predictions, and distorted evaluations of the impact of policy actions. On the other hand, the activity-based approach precludes illogical mode-trip chains by using "tours" as the basic elements to represent and model travel patterns.

The third major difference between the trip-based and the activity-based approaches is in the way the time dimension of activities and travel is considered. In the trip-based approach, the time is reduced to being simply a "cost" of making a trip and a day is viewed as a combination of broadly defined peak and off-peak time periods. On the other hand, activity-based approach views individuals' activity-travel patterns are a result of their time-use decisions within a continuous time domain. Individuals have 24 hours in a day (or multiples of 24 hours for longer periods of time) and decide how to use that time among (or allocate that time to) activities and travel (and with whom) subject to their socio-demographic, spatial, temporal, transportation system, and other contextual constraints. These decisions determine the generation and scheduling of trips. Hence, determining the impact of travel demand management policies on time-use behavior is an important precursor step to assessing the impact of such polices on individual travel behavior.

The fourth major difference between the two approaches relates to the level of aggregation. In the trip-based approach, most aspects of travel (number of trips, modal split, etc.) are analyzed at an aggregate level. The study area is divided into several spatial units labeled as Traffic Analysis Zones (TAZ). Then, the total numbers of trip exchanges are estimated for each pair of TAZs by each travel mode and by each route, during each coarsely defined time of day. Consequently, trip-based methods accommodate the effect of socio-demographic attributes of households and individuals in a very limited fashion, which limits the ability of the method to evaluate travel impacts of long-term socio-demographic shifts. The activity-based models, on the other hand, have the ability to relatively easily accommodate virtually any number of decision factors related to the socio-demographic characteristics of the individuals who actually make the activity-travel choices, and the travel service characteristics of the surrounding environment. Thus the activity-based models are better equipped to forecast the longer-term changes in travel demand in response to the changes in the socio-demographic composition and the travel environment of urban areas. Further, using activity-based models, the impact of policies can be assessed by predicting individual-level behavioral responses instead of employing trip-based statistical averages that are aggregated over coarsely defined demographic segments.

2.3.2.4 Transport and Land Use Models

As explained earlier, the importance of integrating transportation and land use properly in the travel demand estimation process has been well identified. Here, building models can be seen as the only method developed so far to integrate the transportation and land use and, modeling this complex integration has become a fashion in transport and its allied disciplines. In addition finding new ways and means to model this complex integration of transport and land use has become a popular research area among both the academics and industrial practitioners in relevant fields. Rather than saying travel demand models, the models of this nature have popularly been named as transport and land use models. Lots of transport and land use models are presently in operation throughout the world while 90% of them are from developed countries. Though, there are many arguments prevailed about the structure and accuracy, those models provide an immense support for planners, engineers and also for other professionals for taking precise decisions on future. Still there is no proof to say that any model developed until now is capable of handling this situation in 100%. Each model is with its own prospects and constraints.

Whether it is trip-based or activity-based, the transport and land use model is the ideal solution for present day travel demand estimations.

2.3.2.5 Conclusion

In transport planning, the travel demand estimation plays a very important role. Due to huge complexity of the travel demand estimations as it involves with lots of mathematical calculations, statistical relationships, high amount of past and present data, predictions, expert knowledge of diverse disciplines and support from different authorities, the most practical solution for better travel demand estimations is the use of models, which are primarily called as transport models.

Scholars widely argue the huge relationship of transportation with land uses and most of the existing urban issues have been occurred because of neglecting the complex interaction between transport and land use. Therefore, it is compulsory to integrate the land use aspect in travel demand estimations specially the induced travel changes due to the land use changes and induced land use changes due to travel changes. Further, decision makers now have come to a position to take decisions thinking both transportation and land use as one unit. As such, now, transport models integrating the land use aspect have emerged as transport and land use models. The complexity has become more worsen with the integration of land use aspect for both travel demand estimations and, transport and land use models.

It can be observed that 90% of travel demand estimations are done through transport and land use models. Scholars use different approaches for the preparation of transport and land use models and each of these approaches has its own advantages and disadvantages. Further, it can be hardly shown another field, which has been undergone many experiments and researches like modeling the integration of transport and land use.

2.4 Review of Transport and Land Use Models

2.4.1 Introduction

It can be observed, by today, that many transport and land use models are in action throughout the world in order to characterize the complex interaction between transport and land use. All transport and land use models are location-based because of the different travel patterns that each location undertakes. Therefore it is so hard to apply an already developed transport and land use model for a different location. But reviewing the existing models will provide a better theoretical and practical foundation to build a new one. Here, twelve most popular transport-land use models were selected and reviewed in terms of most important aspects such as input data and types, data modeling methods, outputs generated, spatial techniques and user interfaces. While selecting the transport-land use models, several criteria were followed: 1) models, which have given equal priority to both transport and land use, 2) models following different approaches, 3) models representing all over the world, 4) models, which have been applied for different cities, 5) models, which are in operation presently, 6) models developed within last two decades, 7) last editions of models and 8) models, which were used and are being used in Sri Lanka.

2.4.2 Selected Transport and Land Use Models

CAST: CAST stands for City Analysis Simulation Tool. It is an integrated model of land-use, population, transport, and economics. CAST was developed by Dr. Lubo Jankovic and colleagues.

METROSIM: METROSIM is a micro-economic land use and transport model developed for New York Metropolitan Area by Anas. This model has evolved since the early 1980s.

URBANSIM: URBANSIM is an operational model of urban land and floor space markets developed by Professor Paul Waddell for Hawaii, Oregon and Utah, USA.

MEPLAN: The MEPLAN framework is contained in proprietary software developed by Marcial Echenique and Partners Ltd in the UK, a private consulting firm. It draws on 25 years of experience in practical integrated urban modeling, with work on the software package itself beginning in 1985. It has been applied to over 25 regions throughout the world, including Sacramento, California and the Cross-Cascades Corridor in the US.

TRANUS: The TRANUS package is proprietary software developed by Modelistica in Venezuela, a private firm run by Dr. Tomas de la Barra. TRANUS has been applied to a number of regions in Central and South America and in Europe.

DELTA: DELTA is a land use-economic modeling package developed by Davids Simmonds Consultancy, Cambridge, UK. The first application of DELTA was for Edinburgh. Since then, DELTA has been used by numerous projects.

PTOLEMY: PTOLEMY is a strategic land use and transport interaction model for the East Midlands Region. WSP developed PTOLEMY for a consortium of partners including the Highways Agency, East Midlands Regional Assembly (EMRA), East Midlands Development Agency (EMDA), Government Office of the East Midlands (GOEM) and East Midlands Airport.

ITLUP: The Integrated Land Use Transportation Package (ITLUP) is owned by S.H. Putman Associates. The first version came on 1973. This development was the first successful attempt at a full integration of land use and transportation models.

POLIS: The Projective Optimization Land Use Information System (POLIS) was developed by Prastacos for the Association of Bay Area Governments. POLIS is currently used in the San Francisco Bay Area.

ILUMASS: Integrated Land Use Modeling and Transportation System Simulation (ILUMASS) model was developed by seven Research Institutes of German. The ILUMASS model was first calibrated with data of the urban region of Dortmund in the eastern part of the Ruhr area and tested in experimental scenarios of land use and transport development.

TRANSPLAN: TRANSPLAN was developed by the Transportation Engineering Division of University of Moratuwa, Sri Lanka. TRANSPLAN may be seen as the initial step in developing such a comprehensive transport planning software for Sri Lanka.

STRADA: System for Traffic Demand Analysis (STRADA) is a package system for transport forecasting which runs on windows. This was developed by the Japan International Cooperation Agency (JICA) for the purpose of using in developing countries, and sharing of databases. Presently, Road Development Authority of Sri Lanka mainly uses the STRADA for the decision making process.

2.4.3 Review of Models

2.4.3.1 URBANSIM

Several input data used here are tax assessing data (land values, residential and non-residential improvement values), business establishment data, employment data, census data, real estate indicators, GIS overlays representing environmental (wetlands, floodways, stream buffers, steep slopes, or other environmentally sensitive areas), political and planning boundaries (city, county, traffic zones, urban growth boundaries), and a location grid. In model implemented area, each household is with household income, size, age of head, presence of children, and number of workers. The data store represents locations using grid cells of 150 by 150 meters, which contain an area just over 5.5 acres, where cell size can be modified. Different policies such as comprehensive land use plans, infrastructure plans, urban growth boundaries, and development restrictions on environmentally sensitive lands are linked to locations at a grid cell, zonal, municipal, county, or metropolitan scale. In data modelling, made out of a set of software tools that represent over six core models and other sub models, the approach followed by the URBANSIM is disaggregate and based on predicting changes over small time steps, in economic terms, which is called disequilibrium. The modeling process also involves non-spatial models such as economic and demographic transition models to release more accurate outputs. The model is facilitated to receive the views from planners, policy makers and the public. Among the outputs are, predicting the pattern of accessibility by auto ownership level, the creation or loss of households and jobs by type, movement of households or jobs within the region, location choices of households and jobs from the available vacant real estate, the location, type, and quantity of new construction and redevelopment carried out by developers and the price of land at each location. These outcomes are generated on an annual basis, and implemented as scheduled events while large-scale development projects are scheduled as per the necessity with multiyear timetables. Outputs are created also at the grid cell level, and also summarized by traffic zones and for the regions as a whole, besides outputs are written in a standard format for ease of loading into Arc View, Excel, or other common desktop tools. GIS is used as the key spatial technique here.

The interface is built upon using open source approach to provide free access to the source code, and to make model more open to scrutiny and to further extension and adaptation to emerging requirements for modeling. The user interface of the model is focused on the interaction of the user with the inputs to each scenario comprised with development policies and allows specification of desired output files and designation of specific simulation years for which to generate the outputs.

2.4.3.2 METROSIM

Census data, land use data (commercial, residential, vacant and), real estate demand and prices, labor details, job assignments, transport data like travel time and cost, trips for work and shops, housing market such as housing rent, commercial space with rents have been mainly used in the METROSIM Model as inputs. METROSIM takes an economic approach to modeling housing and land-use location. The model embodies the discrete choice method with economically-specified behavior and a market clearing mechanism. Final outcomes of METROSIM are to evaluate transportation projects and travel related changes, land use controls, employment growth scenarios, income growth and other policies or forecast changes. METROSIM can produce a one-shot long run equilibrium forecast for transportation and land use in a metropolitan area, or it can operate in annual increments and produce yearly changes to transportation and land use from the existing situation until convergence to a steady state is achieved. But, it can be identified that METROSIM has a limited opportunity to deal with an external travel demand model.

2.4.3.3 CAST

Other than the main input data, which is land use, range of supporting data have been used by CAST such as population profile (birth/death rates, education/skills, population change, and household change and movement, immigration data a), economic activity (employment data, expenditure on the many goods, services and taxation, inflation, investment data), environmental data (poll), real estate analysis, building levels and standards, etc. CAST uses the ideas of complexity and develops upon cellular automata approaches with the aim of capturing the key process within cities. CAST recognizes the extended networks of cell connections while also understanding that the connections are not equal as proximity, road network, etc. create an uneven geography of connections. The model uses a raster based grid which divides the city into cells, usually of one hectare (100 meters by 100 meters). The classification of the cell type is based on the majority land use type. The CAST model is based on 22 cell types such as water, residential, roads, retail, agriculture, etc. which all have a number of attributes and internal processes. These processes define the cell connectivity and transformation of inputs received from other cells into outputs, as well as internal consumption for each cell.

The primary outcome of CAST studies is land use, the changes, expansions and contractions. Further, model provides the opportunity to explore different scenarios of actions in development, planning, policy and infrastructure provision. The model is developed in Java and Java3D programming languages. GIS is another spatial technique used here. The interface allows adding, if there is a necessity, global actions such as the state of the world economy, in-ward and out-warding population, planning policies, etc. to influence the actions on cells. The user can also supplement the GIS input by adding any of the 22 cell types using a manual input facility of CAST. Using the graphical user interface, this behavior can be displayed as a number of different attributes of cells, thus showing dynamic maps of cell types, cell resources/fitness, population, and various other attributes. A three-dimensional view of these attributes also can be generated.

2.4.3.4 DELTA

Land use data, building data and their rent and prices, data on disciplines of geography, economics, demography, employment, environment, transport demand and movement are considered as main inputs. The DELTA was built upon the START model of Edinburgh, which is an incremental model. Moreover, the basic choices of model type lie between aggregate and disaggregate techniques. Within DELTA, two main sub models can be seen, namely Land Use Model and the Transport Model, while activity modeling in DELTA is incorporated into three sub models, dealing with demographic transitions and economic changes; location or relocation, property markets, and change in the use of labor. The land use model, which deals with both space and activities, is considered as a general model of urban change, in which the influences of transport on land use are just some of many influences at work. In particular, transport or accessibility is considered to be an influence on the process of change rather than a controlling factor in itself. The model also considers the impact of transport through its effects on the local environment.

The mean of development used here is generally modeled as a speculative one, that is, the commissioning of buildings by their prospective occupier is not explicitly considered except where major development are exogenously introduced. The main outcome is finding the impacts of transport to land use changes and vice versa. Among the other outputs predicting the accessibilities, number of households, persons, jobs, and retail floor space by zone, etc. are expected. The model is basically used for making assumptions only for either one or two years, but only requirement of the software design is that all the periods should be of equal length.

2.4.3.5 MEPLAN

MEPLAN uses travel time and cost, road and public transport network, the ownership of cars and the availability of buses, trains and other forms of travel, land cost and elasticity of demand for land, and incomes as fundamental variables. This model is derived from the Lowry model, but considers more comprehensively the housing market and its influences on the location of the population. It also includes the now classic bid-rent theory where individuals select their residential locations as a compromise between their willingness to pay for residence at a location and the related transportation cost. MEPLAN also adopts many of the fundamental concepts of monocentric theory. Further, MEPLAN is based on the concept that at any level land use and transport affect one another.

The spatial pattern of land use and economic activity creates the demand for transport to move people and goods between places. The availability and efficiency of transport influences the choices people make about where they live and work, where employers locate their business and where developers choose to build. MEPLAN analyses these relationships, and predicts and evaluates the many impacts that planning decisions will have on land-use and transport by considering the retroactive effects congestion can have on the friction of distance, trip generation, trip distribution and residential location. MEPLAN principally looks at the market demand and supply for both land and transport.

2.4.3.6 PTOLEMY

Information on population, households, dwellings and employment are inputs to reflect land use activities. To obtain transport measures, multi-modal network together with information on travel by vans and lorries, road capacities, and additional costs and times from congestion are applied. Some of other inputs are alternative economic growth scenarios, development schemes, accumulated effects of small scale developments (e.g. infill, densification, and windfall sites), development tax and incentives, highway improvements and public transport schemes. PTOLEMY is structured around two main models; a land-use model and a transport model. The transport model is made up of two sub models, which are transport demand model and transport assignment model. Inside these models, sub processes comprises transport accessibilities, planning data and travel demand, transport cost by mode and modal trip matrices. Land-use model predicts service employment location, housing demand, and car ownership by zone, from which travel is generated as a derived demand. Social mix of population and ratio of employment against population are some extra outputs generated land-use model itself. Transport demand model estimates the outward and return journeys between where travel is produced and where it is attracted to. Further, it outputs the proportion of journeys taking place in the morning peak period, passengers' choice among all means of travel including mechanized modes, walking and cycling, movements of cars, vans and lorries, passengers on rail and tram, travel costs including user charges for using the network and parking, and travel times including road congestion. In addition, combining both models, social impacts of accessibility changes, wider economic benefits, and percentage of population in catchment for opportunities are produced.

In overall, PTOLEMY is to provide estimates of the likely location of the population and households together with their demand for travel by primarily evaluating a number of land-use and transportation interactions. Moreover, the model is equipped with relevant spatial techniques. The model has provided the room to interface with other city models such as SATURN, etc. PTOLEMY is uniquely placed to test strategic land use and transport policy issues, because of its wide geographic coverage and comprehensive representation of the land use and transport responses to policy interventions.

2.4.3.7 ITLUP

ITLUP needs data on employment for each distinct employment sector, household details, population per zone and per category (four income groups are usual), inter zonal travel cost, land allocation per zone and per activity, the transportation network (links, speed, capacities) of the area, trips per person, purpose and travel times per mode, etc. The ITLUP equations are non-linear. Further, ITLUP, an extension of the Lowry model, is commonly composed of three major components, namely EMPAL (Employment Allocation Model), DRAM (Disaggregated Residential Allocation Model) and Travel Demand. ITLUP forecasts in five year steps. The model output of a run for one forecast year becomes the input for the next run. EMPAL is to predict, from an exogenous economic forecast, the location of employment in each analytical zone. It mimics, to some extent, an industrial location procedure where factors such as accessibility and labor are considered. Later, with the location of employment given by EMPAL, DRAM calculates the location of households, often from a distance decay perspective where empirical factors such as commuting time are considered. Then it calculates the amount of trips generated from home-to-work, home-to-shop and work-to-shop purposes, income group and mode, average travel time per origin/destination per mode, and travel energy per purpose per social/car ownership group and mode. Finally, Travel Demand, passing four stages process, provides feedbacks on the friction of distance, employment location and trip distribution among other outputs, are population per income group and working/non-working category, land allocation per activity, vacant lands. Also, it has an option to produce air pollution information while no space to produce planning and economic indicators. All these are organized in such a way that the future land use patterns are affected by both previous land use patterns and previous levels of accessibility. Graphics modules are available with ITLUP to produce maps and networks. Further, ITLUP has some versions like TELUM, etc., which use GIS. In most occasions, totals and statistical details on a regional basis, in zonal levels, are presented.

2.4.3.8 TRANUS

Main inputs are land data for example type, use, price, rent, density, interactions, real estate market and GIS maps, population data by socio-economic groups and zone, economic activities such as employment data by type and zone, salaries, profit taxes, imports, etc., and Transport network details like nodes, links, services, fares, operating costs, values of time, preferences, congestion, waiting time, etc. TRANUS development is closely related to the work of Leontief in 1936 on the input-output accounting framework. In TRANUS, the discrete choice approach is applied to all components of the urban/regional and transport system, from trip generation to mode choice, location choice, land use choice, and others. TRANUS is a long chain of linked discrete choice models where unique characteristic is that TRANUS keeps total theoretical consistency throughout the decision chain. In TRANUS, the movements of people or freight are explained as the results of the economic and spatial interactions between activities, the transport system and the real estate market. Sequentially, the accessibility that results from the transport system influences the location and interaction between activities, also affecting land rent. Economic evaluation is also part of the integrated modeling and theoretical formulation, providing necessary tools for the analysis of policies and projects. In TRANUS, it is possible to use small samples surveys to calibrate the modeling process to result the reliable outputs at a reasonable cost and time.

The TRANUS is specially designed for the simulation of the probable effects of projects and policies of different kinds in cities and regions, and to evaluate the effects from economic, financial and environmental points of view. It is also possible to assess the effects of urban regulations or housing projects on the transport system. The integrated nature of the model also makes estimations of origin-destination matrices for several traveler types, modes and trip purposes. The modeling process can perform both long term and short term projections for strategic and detailed studies respectively. The latest versions of TRANUS consist of advantages of newly software, especially word processors, spreadsheets, geographic information systems (GIS) and traffic models. The interface is equipped with object oriented graphical interface called TRANUS User Cell (TUS) that facilitates, like setting up a database, importing/exporting data to and from other applications, running the models, presenting maps with data and results of the simulations and producing numeric reports and apply to any scale, from detailed urban level to regional and national models.

2.4.3.9 POLIS

Planning and development policies, detailed land use information, countywide estimates of household demand, population, employed resident growth, and details on manufacturing and wholesale trade, agriculture, transportation, communications, utilities and finance, Insurance, real estate, retail trade and services are used as inputs to the POLIS.

The model can be stated as a single mathematical program which seeks to maximize jointly the locational surplus associated with multimodal travel to work, retail, and local service sector travel, and, significantly and jointly agglomeration benefits accruing to basic sector employers. Two basic economic sectors namely transportation and finance, and insurance and real estate have been modeled here. The allocation process in POLIS is based on several criteria, some reflecting the behavior of individuals and some describing physical and planning constraints. Travel-to-work and shopping behavior, the availability and attractiveness of housing, current levels of nearby employment determine residential choice. Retail activity is located in proximity to population centers to maximize the sales revenue. The location patterns of the other industries are influenced by the accessibility to labor supply, the proximity to other similar industries and local development policies. POLIS also does the allocation of population, housing, and employment at the sub-county (zonal) level. This does in housing, employment and trip flow patterns to be consistent with each other and elimination of land use constraints.

2.4.3.10 ILUMASS

Major input data are populations of households, dwellings, non-residential buildings, firms, and vehicles as well as the road and public transport networks. Among other inputs are data on schools, universities, car ownership, land prices, household income and parking facilities. ILUMASS aims at embedding a microscopic dynamic simulation model of urban traffic flows into a comprehensive model system that incorporates changes of land use, the resulting changes in activity behavior and in transport demand, and the impacts of transport and land use on the environment. For each forecasting year, the distributions of households, persons, firms, and workers are passed to the micro simulation modules forecasting travel and freight transport demand and dynamic traffic assignment. The traffic flows, link roads, and travel times and cost so generated are fed back to the land-use model in which they, through accessibility, affect the behavior of developers, households, and firms. In addition they serve as input to the environmental modules which calculate the resulting environmental impacts of transport and land use. These, in turn are fed back to the land-use models and affect the location decisions of developers, households, and firms. The model also can be used to study the likely impacts of various policy alternatives in the fields of land use and transport planning. The integrated model will be calibrated using data from household activity and travel surveys conducted in the study region and validated using aggregate time series data of population, housing, and employment as well as data from traffic counts in the study region. GIS based techniques are used to disaggregate zonal data to raster cells in order to bridge the data gap between zones and raster cells.

2.4.3.11 TRANSPLAN

TRANSPLAN model has been developed since 1995. It is presently the version 4. The present system has a number of capabilities to obtain highway network statistics such as number of trips between nodes or zones, minimum paths between zones or nodes, link flows, speed of links, vehicle hours and vehicle kilometers of the network, etc. TRANSPLAN uses many socio-economic data such as population, households, car ownership data, employment and unemployment data, economic infrastructures, building materials, etc. There are 2243 links in the TRANSPLAN model and each link is filled with many details such as starting node, ending node, sidewalk width, shoulder width, length, no of residential lands, no of industrial and commercial land, no of bare and agricultural lands, etc. Also there are 1624 nodes with details such as node name, node weight, node control type, node area, node elevation, node status, etc. By all details, TRANSPLAN has given enough information for users to be familiar with the transport network in Sri Lanka. TRANPLAN has two main algorithms as equations, which have been developed through the regression analysis technique. Here, above mentioned socio-economic data are used as independent variables to generate the desired outputs. Lacking of the spatial integration can be taken as one of main disadvantages comparing other models used in present day.

2.4.3.12 STRADA

STRADA is a technical model that describes the dynamic interactions of traffic flows within a network. A network here is defined by zones, nodes within the zones, links within and between nodes, and centers of gravity as intersections of hypothetical links. The links connect a maximum number of nodes and reflect the dispersed nature of trip generation and attraction. The network is built up over a program period from an existing based network that is defined by actual traffic counts and origin-and-destination information. The base network serves as the basis for the evolving future networks. As the main modeling technique, STRADA uses the four stage modeling process involving various techniques at each stage to analyze an aggregated personal activity data by zone. Other than those basic transportation related inputs, many socio-economic data are used to generate the outputs. The main output of the STRDA model is to make passenger demand forecasts for future scenarios. Selecting the most appropriate strategies, assessing of projects, modal share predictions and cost estimations are among other main outputs. The STRADA consists of 17 programs such as Trip Matrix Builder, OD Calibrator, Matrix Manipulator, GIS Converter, etc., thus, STRADA combines several programs together to generate outputs as necessary. The new version of STRADA has upgraded the ease of conversion between the GIS and the STRADA data format.

2.5 Analysis of Models

2.5.1 Input Parameters

2.5.1.1 Census Data

Census data is the most stirring input to the each and every transport and land use model. The most regular census data of selected models comprises with birth and death rates, population data, education data, immigration data, number of households, and each household details such as household income, household size, age of the head, number of children and number of workers. Moreover, it seems that some models make use of analyzed census data over the years as inputs such as population change, educational skills, household change and movement, housing demand, etc.

TRANSPLAN includes basic census data such as population and number of households. Other than the MEPLAN, all other models acquire birth and death rates as inputs. Both immigration and emigration data are being used by URBANSIM, METROSIM, CAST, DELTA and TRANUS. Processed census data such as population change and educational skills, are being used by URBANSIM, METROSIM, CAST, DELTA, ITLUP and TRANUS. It can be seen that URBANSIM, METROSIM, CAST, DELTA and TRANUS employ many more census data as inputs.

URBANSIM, METROSIM, PTOLEMY, ITLUP and ILUMASS consider mostly household income and size. All these five models and CAST as well make use of household change and household movement processed from household data over the years. In addition, MEPLAN employs household income data. Household data such as age of the head, presence of children and number of workers are used as other census input data in URBANSIM, METROSIM and ITLUP. Further, ILUMASS uniquely uses the data on schools and universities.

2.5.1.2 Transport Data

Transport data is also a popular input to these models, where it comes in different forms. Travel time and cost data are being used by METROSIM, MEPLAN, ITLUP and TRANUS. METROSIM, DELTA, STRADA and ITLUP use number of trips. Transport network data, such as road length, road width, roughness, curvature, median width, availability of shoulders and their parameters, etc., is employed by MEPLAN, PTOLEMY, ITLUP, TRANUS, STRADA and TRANSPLAN.

Speed data and parking data are merely taken in the ITLUP and TRANSPLAN and, ILUMASS and TRANSPLAN respectively, while TRANSPLAN, MEPLAN and ILUMASS only use car ownership data out of ten models. Exceptionally, TRANUS also analyzes the data on different aspects of the transportation as taking congestion pricing, fares, preferences, operational costs and service levels (comfort level, easiness of accessibility, etc.) data. Excluding the TRANUS, only PTOLEMY uses congestion pricing as one of inputs.

2.5.1.3 Employment Data

Employment data can be seen as a further interesting input and this facet can be categorized mainly into four aspects namely job assignment data, labor details, job sectors and job salaries. Out of the eleven models, eight models namely TRANSPLAN, URBANSIM, METROSIM, CAST, ITLUP, TRANUS, PTOLEMY and POLIS apply both labor details along with the assignment data. TRANSPLAN consists with five employment categories namely state sector, semi-government, public sector, industrial and private sector in the employment data set. Even out of above eight models, POLIS takes labor details in their category wise as well. Here, salaries data only used in the TRANUS.

2.5.1.4 Land Use Data

Land use data is used by seven models namely URBANSIM, METROSIM, CAST, DELTA, ITLUP, TRANUS and POLIS. Built up areas, wetlands, floodways, stream buffers, environmental sensitive areas, political and planning boundaries, transportation network, location grids, steep slopes can be seen as some of the common geographic input parameters. Out of these seven models, except the METROSIM and POLIS, five models use these land use data in GIS form. GIS can be seen as a popular platform for acquiring most of land use data in today's transport and land use models. Moreover, it is interesting that TRANSPLAN has given some effort to accommodate land use data in the means of taking residential, industrial and commercial, bare and agricultural and, other lands along the links identified at the road network database.

2.5.1.5 Incorporation of Projects, Plans and Policies

Incorporation of policies can be seen in five models namely URBANSIM, TRANSPLAN, PTOLEMY, STRADA and POLIS. URBANSIM and POLIS furthermore involve land use plans, infrastructure plans, urban growth boundaries, environmental sensitive land proposals and transport schemes including highway improvement projects as well. PTOLEMY also uses all above plans and policies except urban growth boundaries and environmentally sensitive lands.

2.5.1.6 Economic Data

URBANSIM, METROSIM, MEPLAN, TRANSPLAN, ITLUP, POLIS and ILUMASS use no economic data significantly. Expenditures of goods and services are used by CAST, DELTA and TRANUS. Other than the expenditure data, TRANUS also uses inflation data, economic growth scenarios, investment details and, import and export statistics. CAST only uses inflation data and investment details, while PTOLEMY occupies only economic growth scenarios. Different types of tax data are used by URBANSIM, CAST, PTOLEMY and TRANUS.

2.5.1.7 Environmental Data

It is remarkable that environment data as inputs have been used merely on CAST and DELTA.

2.5.1.8 Real Estate Data

Different aspects of real estate are other common inputs to these models. METROSIM, CAST, DELTA, STRADA and TRANUS use real estate demand data, real estate prices and, housing markets and rents. But MEPLAN only uses real estate demand data and prices, while ILUMASS uses only real estate prices. Land values have been used in URBANSIM and MEPLAN. URBANSIM uniquely uses residential and non-residential improvement values, and business establishment data. Finally CAST and DELTA use building levels and standards as one of the inputs.

Table 2.1 Input Parameters

Input Parameters		URBANSIM	METROSIM	CAST	DELTA	MEPLAN	PTOLEMY	ITLUP	TRANUS	POLIS	ILUMASS	TRANSPLAN	STRADA
Tax Assessing Data		■		■			■		■				■
Environmental Data	Pollution			■	■								
	Other				■								
Land values		■				■							
Transport Data	Travel Time		■			■		■	■				■
	Cost		■			■		■	■				■
	Number of Trips		■		■			■					■
	Transport Network					■	■	■	■			■	■
	Speed							■				■	■
	Ownership of Cars					■					■	■	
	Prices (time and cost) from Congestion						■		■				■
	Fares								■				
	Preferences								■				
	Operational Costs								■				
	Services								■				
	Parking Facilities										■	■	
Residential improvement values		■											
Schools and Universities											■		
Non-residential improvement values		■											
Business establishment data		■											
Employment data	Job Assignments	■	■	■			■	■	■	■			
	Labor Details	■	■	■			■	■	■	■		■	
	Sector Analysis									■			
	Salaries								■				
Census data	Other Census Data: Birth/Death Rates	■		■	■		■	■	■	■	■	■	
	Population Change	■		■	■		■	■	■	■	■		
	Education Skills	■		■	■			■	■				
	Immigration Data	■		■	■				■				
	Other	■	■	■	■				■				

Input Parameters			URBANSIM	METROSIM	CAST	DELTA	MEPLAN	PTOLEMY	ITLUP	TRANUS	POLIS	ILUMASS	TRANSPLAN	STRADA
	Household data	Household Change	■		■			■	■			■		
		Household Movement	■		■			■	■			■	■	
		Income	■				■	■	■			■		
		Size	■					■	■			■		
		Age of head	■						■					
		Presence of children	■						■					
		Number of workers	■						■					
		Housing Demand									■			
Land Use Data	Other Land Use Data		■	■	■	■			■	■	■		■	
	GIS overlays	Wetlands	■		■	■			■	■				
		Floodways	■		■	■			■	■				
		Stream buffers	■		■	■			■	■				
		Environmental sensitive areas	■		■	■			■	■				
		Political & planning boundaries	■		■	■			■	■				■
		Location grid	■		■	■			■	■				
		Steep slopes	■		■	■			■	■				
Different policies	Land use plans		■					■			■		■	■
	Infrastructure plans		■					■			■		■	■
	Urban growth boundaries		■								■		■	■
	Environmentally sensitive lands		■								■		■	
	Transport Schemes		■					■			■		■	■
	Highway Improvement Schemes		■					■			■		■	■
	Demand			■	■	■	■			■				■

Input Parameters			URBANSIM	METROSIM	CAST	DELTA	MEPLAN	PTOLEMY	ITLUP	TRANUS	POLIS	ILUMASS	TRANSPLAN	STRADA
Real Estate	Prices													
	Housing Market & Rent													
Economic Activity Data	Expenditures	Goods												
		Services												
	Inflation													
	Economic Growth Scenarios													
	Investment													
	Imports													
Building Levels and Standards														

2.5.2 Output Parameters

2.5.2.1 Trip Generation and Attraction Data

Origin-Destination (O-D) matrix is an input to the most of the transport and land use models. Also it can be seen that it acts as one of the main outputs as well. Examples for those are PTOLEMY, ITLUP, TRANUS, TRANSPLAN, STRADA and ILUMASS. Out of these five models, three models namely ITLUP, TRANSPLAN and TRANUS release O-D matrix comprised not only with number of trip generates and attracts but also description of them according to trip purpose, income group, transport mode, travel time, fuel consumption, travel cost, etc.

2.5.2.2 Traffic Data

Other than the METROSIM, TRANSPLAN, CAST, MEPLAN and POLIS, all other transport and land use models reviewed here estimate the traffic of each route in the study area. By analyzing further, TRANSPLAN, STRADA, URBANSIM and PTOLEMY calculate this figure by transport mode as well. Moreover, PTOLEMY gives complete description of car-ownership data as an output.

Travel time and travel cost predictions are an output of TRANSPLAN, PTOLEMY and ILUMASS. Further, PTOLEMY, STRADA and TRANSPLAN estimate the congested routes with the time parameters as well. Other than that ITLUP and STRADA also predicts the travel times. Exceptionally, TRANSPLAN makes an estimate of vehicle kilometers, vehicle hours and vehicle operating costs as well.

2.5.2.3 Change of Locations of Houses and Jobs

Predicting the change of locations of houses and jobs is another popular output of these models. Most models here treat this aspect as the second best output of the model. While URBANSIM, DELTA, PTOLEMY, ITLUP and POLIS consider both movements of houses and jobs, METROSIM and ILUMASS analyze only change of locations of jobs and change of locations of houses respectively. Although these two aspects can be considered as under the change of land uses, still decision and policy makers like to distinguish these two aspects as unique outputs, as most of major decisions are based upon those. Further, forecasting population distribution is another imperative output of DELTA, PTOLEMY, ITLUP and POLIS.

2.5.2.4 Change of Land Use

URBANSIM, METROSIM, CAST and ITLUP foretell the change of the land uses in coming years. Here, changes of built-up areas (residential areas, commercial areas and industrial areas), forest covers, water bodies, road network, etc. are major concerns, it appears. With the ability of forecasting changes of land uses, these four models furnish directives for decision makers to put forward land use controls. In addition to predicting change of land uses, URBANSIM also predicts the upcoming prices of lands and further, ITLUP predicts vacant lands. Even though, there is no declaration about changes of land uses, TRANUS predicts the land rents.

2.5.2.5 Evaluation of Projects

Further, all these models are capable of evaluating different types of both macro and micro scale projects, in the areas of compatibility with present situation, ongoing projects and effects to the various types of infrastructures. But, it seems that different models do it in different approaches, also some models accomplish it merely covering one or two possible aspects while others do it more multifaceted way covering all possible aspects. Five major aspects can be noticed here namely economic, social, financial and environmental aspects and, interaction with land uses. Mainly, economic aspect popularly considers investments, expenditures, employment, payroll, accessibility (raw materials, labor and market), congestion pricing, prices of goods and services, reliability issues, tax revenue by travel, while social aspect considers safety, equal opportunities, health issues, community severance, forced relocation, fair competition, cultural diversity, security, stress, level of service (comfort and satisfaction), historical and cultural resources, etc. Further, environmental aspect covers greenhouse gas emissions, noise, visual quality, use of resources and raw materials, fuel consumption, releases to water, releases to land, etc. It seems that TRANUS and STRADA have the highest capability in evaluating travel related changes of projects in the means of covering greatest number of possible aspects. TRANUS evaluates the interaction with land uses, economic aspects, environmental aspects and financial aspects of travel related changes, where it misses only social aspects. Here, TRANUS and STRADA specifically involve with evaluation of housing projects and preparation of urban regulations. PTOLEMY also covers the interaction with land uses, social aspects and economic aspects of travel related changes, where it misses only environmental aspect. ITLUP evaluates both economic and environmental aspects of travel related changes. Other than that CAST, DELTA and MEPLAN evaluates the interaction with land uses while ILUMASS evaluates the environmental aspect of travel related changes of projects.

2.5.2.6 Preparation and Evaluation of Policies

Out of the ten models, it is remarkable that almost five models have touched even the preparation and evaluation of policies. Those are METROSIM, CAST, TRANUS, STRADA and ILUMASS. Here, ILUMASS pays special attention on predicting the behavior of developers.

Table 2.2: Output Parameters

Output Parameters		URBANSIM	METROSIM	CAST	DELTA	MEPLAN	PTOLEMY	ITLUP	TRANUS	POLIS	ILUMASS	TRANSPLAN	STRADA
Traffic of routes	Normal	■			■		■	■	■		■	■	■
	By transport mode	■					■					■	■
Change of locations of houses		■			■		■	■		■	■		
Change of location of jobs		■	■		■		■	■		■			
Change of Land uses		■	■	■				■					
Prices of land		■											
Evaluating travel related changes			■									■	■
Land use controls			■										
Preparation/Evaluation of policies			■	■					■		■		■
Evaluation transport-land use projects/decisions				■	■	■	■		■				
Population distribution					■		■	■		■			
Change of retail floor space					■								
Evaluation land use-economic projects/decisions						■							
Market demand and supply for both land and transport						■							
Car Ownership							■						
O-D Matrix	Complete							■	■			■	■
	Normal						■				■	■	■
Travel Time Prediction							■	■			■	■	■
Travel Cost Prediction							■				■	■	■
Congestion Prediction	Normal						■					■	■
	With Time						■					■	■
Social impacts with travel changes							■						
Economic impacts with travel changes							■	■	■				
Change of Locations of Industries								■		■			
Vacant land prediction								■					
Environmental impacts with travel changes								■	■		■		
Land rent prediction									■				

Output Parameters	URBANSIM	METROSIM	CAST	DELTA	MEPLAN	PTOLEMY	ITLUP	TRANUS	POLIS	ILUMASS	TRANSPLAN	STRADA
Financial impacts with travel changes												
Evaluation of housing projects												
Evaluation of urban regulations												
Behavior of developers												
Change of locations of business establishments												

2.5.3 Modeling Structure

2.5.3.1 Special Techniques

All models have been developed through algorithms, where those come to action in different forms. An algorithm is a sequence of prescriptive steps that eventually leads to a result as the solution of a problem. It can be observed that some models employ vast number of algorithms while some models barely one algorithm. As an example, while URBANSIM is using six algorithms for separate aspects such as accessibility, land price, mobility and transition, location choice, real estate development and residential land share, the POLIS use only a single algorithm to generate outputs. Accordingly to reviewed models, algorithms can be categorized into two aspects: 1) equations developed from regression analysis, 2) special techniques. Here, CAST uses the ideas of complexity and develops upon cellular automata approaches with the aim of capturing the key processes within cities. The cellular automaton introduced by John Von Neumann is a computational method which can simulate the process of growth by describing a complex system by simple individuals following simple rules. This concept of simulating CAST recognizes the extended networks of cell connections while also understanding that the connections are not equal as proximity, road network, etc. to create an uneven geography of connections. The model uses a raster based grid which divides the city into cells, usually of one hectare (100 meters by 100 meters). The classification of the cell type is based on the majority land use type. The CAST model is based on 22 cell types such as water, residential, roads, retail, agriculture, etc., which all have a number of attributes and internal processes. These processes define the cell connectivity and transformation of inputs received from other cells into outputs, as well as internal consumption for each cell.

ILUMASS aims at embedding a microscopic dynamic simulation model of urban traffic flows into a comprehensive model system that incorporates changes of land use, the resulting changes in activity behavior and in transport demand, and the impacts of transport and land use on the environment. The microscopic traffic flow model establishes the connection between the infrastructure of the city and the individual activity behavior. In that step of the model, the planned trips are realized taking their interaction into account. As a result, information about the practicability of the planned trips is available. That information is used in an iteration process in which plans are rescheduled leading to an equilibrium situation in which all plans are feasible. In addition to this short-term feedback the environmental impact of traffic is assessed and used to influence long-term planning of the simulated individuals. The microscopic module of activity pattern and travel demands was developed by the Institute for Urban and Transport Planning, RWTH Aachen University.

While using the four step modeling process, STRADA model is fully based on the OD matrix data to generate most of the outputs. It appears, most of the other models use equations as algorithms developed from regression analysis to generate outputs, where some equations are linear and some are non-linear. The TRANSPLAN uses three, namely free flow speed model, speed flow model and traffic model, internal equations to estimate the traffic under different socio-economic, road network, and transport policy conditions. Further, POLIS can be stated as a single mathematical program which seeks to maximize jointly the locational surplus associated with multimodal travel to work, retail, and local service sector travel, and, significantly and jointly agglomeration benefits accruing to basic sector employers. Except that, The ITLUP equations are non-linear.

2.5.3.2 Economic Behavior

It can be seen that economic aspect has been greatly concerned by these models to take the relevant outputs. METROSIM takes an economic approach to model housing and land use locations. The METROSIM model embodies the discrete choice method with economically-specified behavior and a market clearing mechanism. The model is formulated in three market equilibriums: 1) labor market equilibrium and job assignment, 2) housing market equilibrium and 3) commercial space equilibrium. The model iterates between these markets and the transportation system for equilibrium of land use and transportation flows. The economic relationship between two aspects namely transportation and finance, and insurance and real estate have been modeled in the POLIS. MEPLAN adopts many of the fundamental concepts of mono-centric theory. With very strong economic and spatial assumptions, MEPLAN try to solve the problem of simultaneous location of firms and households inside the modeling process. Further, in the MEPLAN, spatial pattern of land use is supported by economic activities to decide places, where transport is required to move people and goods. Most importantly, MEPLAN includes travel time and cost, land costs and elasticity of demand for land, and income as fundamental variables, and so can recreate the scenarios that have been investigated in the mono-centric theory.

The bid rent theory, which was later developed by J.H. Von Thunen, who combined it with the notion of transport costs, is a geographical economic theory that refers to how the price and demand for real estate change as the distance from the central business district (CBD) increases. MEPLAN included the classic bid rent theory to find locations, where individuals select their residential locations as a compromise between their willingness to pay for residence at a location and the related transportation cost. Further, METROSIM and TRANUS are indebted to microeconomic theory, in particular to bid rent theory and Alonso’s (1964) theory of urban land markets.

URBANSIM and DELTA make use of economic sub models for the decision making process. A key feature of economic sub model of URBANSIM is the use of an explicit economic accounting approach that traces inter-sectoral spatial and monetary flows of goods and services between producers and consumers (input-output analysis). Economic sub model of DELTA deals with location and relocation of property markets and change in the use of labor. Other than the economic sub models, these two models also are facilitated by demographic sub models.

Most models reviewed here can be seen as random utility models or multinomial logit models, especially METROSIM, MEPLAN, ITLUP, TRANUS and POLIS. The choices at this juncture are predicted on observed characteristics collected through different types of surveys.

2.5.3.3 Based on Earlier Models

The Lowry model was one of the first transportation-land use models developed in 1964 for the Pittsburgh region. Even if its formulation is rather simple, it depicts well the relationships between transportation and land use. The core assumption of the Lowry model assumes that regional and urban growth (or decline) is a function of the expansion (or contraction) of the basic sector. This employment is in turn having impacts on the employment of two other sectors, retail and residential. Its premises were expended by several other models, including MEPLAN and ITLUP, known as "Lowry-type" models.

Few more models can be seen built upon the earlier models. The DELTA was built upon the START model of Edinburgh, which is an incremental model. While, TRANUS development is closely related to the work of Leontief in 1936 on the input-output accounting framework.

2.5.3.4 Aggregate Data vs. Disaggregate Data

Another distinguished difference between models is that, some models calibrate using aggregate data, while other models use disaggregate data or both aggregate and disaggregate data. It seems that most recent transport-land use models are more towards disaggregate. The reasons for this are not only the need for higher behavioral, spatial and temporal resolution stated above, but also methodological reasons. Disaggregate models are easier to implement and calibrate (using stated preference techniques), more parsimonious in their data needs (because they can work with sample data or even synthetic micro data), more flexible with respect to testing new hypotheses or policies and easier to communicate to non-experts and decision makers. DELTA model can be taken as a model, which calibrate the model using both aggregate and disaggregate data. Further, MEPLAN and TRANSPLAN are aggregate models: space is divided into zones, quantities of households and economic activities (called ‘factors’ or ‘sectors’) are allocated to these zones, and flows of interactions among these factors in different zones give rise to flows of transport demand. It can be observed all other models are based on the disaggregate data. Remarkably, STRADA model uses both aggregate and disaggregate models for predictions.

2.5.3.5 Equilibrium vs. Disequilibrium

METROSIM can produce a one-shot long run equilibrium forecast for transportation and land use in a metropolitan area, or it can operate in annual increments and produce yearly changes to transportation and land use from the existing situation until convergence to a steady state is achieved. Moreover, MEPLAN, PTOLEMY and TRANUS are static equilibrium models, which either jump directly to the end-year equilibrium state or are moved from one equilibrium point to the next in typically 5-year steps. But modeling process of TRANUS, STRADA and TRANSPLAN can perform both long term and short term projections for both strategic and detailed studies. Further, ITLUP and may be brought to general equilibrium, but this is normally done. The URBANSIM and STRADA models are based on the “dynamic disequilibrium” approach, where the supply (of real estate) and demand (for housing and places of work), while moving in same direction, never achieve a perfect match (full equilibrium) because of the temporal lag in the response. Moreover, outcomes of URBANSIM are generated on an annual basis, and implemented as scheduled events while large-scale development projects are scheduled as per the necessity with multiyear timetables.

2.5.3.6 Discrete Choice Models

A discrete choice model is one in which decision makers choose among a set of alternatives. To fit within a discrete choice framework, the set of alternatives and the choice set need to exhibit three characteristics: 1) alternatives need to be mutually exclusive, 2) alternatives must be exhaustive, and 3) the number of alternatives must be finite. According to the literature on hand, METROSIM, STRADA and TRANUS can be explored as discrete choice models. The METROSIM embody the discrete choice method with economically-specified behavior and a market clearing mechanism. In TRANUS, the discrete choice approach is applied to all components of the urban/regional and transport system, from trip generation to mode choice, location choice, land use choice, and others. TRANUS is a long chain of linked discrete choice models where unique characteristic is that TRANUS keeps total theoretical consistency throughout the decision chain.

2.5.3.7 Sub Models

As explained earlier, the STRADA model uses seventeen sub models. As earlier expressed, URBANSIM and DELTA make use of economic and demographic sub models. Further, within DELTA, two main sub models can be seen, namely Land Use Model and the Transport Model. Here, the Land Use Model, which deals with both space and activities, is considered as a general model of urban change, in which the influences of transport on land use are just some of many influences at work.

Moreover, PTOLEMY also is structured around two main models: 1) land use model, 2) transport model. The transport model is made up of two sub models, which are transport demand model and transport assignment model. Inside these models, sub processes comprise transport accessibilities, planning data and travel demand, transport cost by mode and modal trip matrices. Land-use model predicts service employment location, housing demand, and car ownership by zone, from which travel is generated as a derived demand. Social mix of population and ratio of employment against population are some extra outputs generated from land use model itself. Transport demand model estimates the outward and return journeys between where travel is produced and where it is attracted to. Further, it outputs the proportion of journeys taking place in the morning peak period, passengers' choice among all means of travel including mechanized modes, walking and cycling, movements of cars, vans and lorries, passengers on rail and tram, travel costs including user charges for using the network and parking, and travel times including road congestion. In addition, combining both models, social impacts of accessibility changes, wider economic benefits, and percentage of population in catchment for opportunities are produced.

Further, ITLUP, an extension of the Lowry model, is commonly composed of three major components, namely EMPAL (Employment Allocation Model), DRAM (Disaggregated Residential Allocation Model) and Travel Demand. EMPAL is to predict, from an exogenous economic forecast, the location of employment in each analytical zone. It mimics, to some extent, an industrial location procedure where factors such as accessibility and labor are considered. Later, with the location of employment given by EMPAL, DRAM calculates the location of households, often from a distance decay perspective where empirical factors such as commuting time are considered. Then it calculates the amount of trips generated from home-to-work, home-to-shop and work-to-shop purposes as per the income group and mode, further, average travel time per origin/destination per mode, and travel energy per purpose, per social/car ownership group and mode. Finally, Travel Demand, passing four stage process, provides feedbacks on the friction of distance, employment location and trip distribution.

Table 2.3: Modeling Structure

Modeling Technique			URBANSIM	METROSIM	CAST	DELTA	MEPLAN	PTOLEMY	ITEUP	TRANUS	POLIS	ILUMASS	TRANSPLAN	STRADA
Unified				■									■	
Composite							■		■	■	■			■
Approach	Economic	Housing		■										
		Land Use Location		■										
		Transport									■			■
		Insurance									■			
		Finance									■			
Cellular Automata					■									
Spatial Interactions										■				
Real Estate Market										■	■			
Mathematical Modeling											■		■	■
Dynamic			■											■
Data Intensive			■											■
Aggregate						■	■						■	■
Disaggregate			■			■								■
Microscopic dynamic simulation model												■		
Micro simulation Techniques												■		

Modeling Technique		URBANSIM	METROSIM	CAST	DELTA	MEPLAN	PTOLEMY	ITLUP	TRANUS	POLIS	ILUMASS	TRANSPLAN	STRADA
Monocentric theory						■							
Random Utility			■			■		■	■	■			
Discrete Choices			■						■				■
Entropy Maximization									■				
Bid Rent Theory			■			■			■				
Microeconomic Theory			■						■				
Equilibrium			■			■	■	■	■				■
Disequilibrium		■											■
Non-Spatial Models	Economic	■			■								
	Demographic	■			■								
Behavior	Economically Specified		■										
Mechanism	Market Clearing		■										
	Complexity			■									
Built Up on	START Model				■								
	Lowry Model					■		■					
	Classic bid-rent theory					■							
	input-output accounting framework (Leontief)								■				
Sub Models	Land Use Model				■		■						
	Transport Model				■		■						
	Transport Model – Transport Demand Model						■	■				■	■
	Transport Model – Transport Assignment Model						■					■	■
EMPAL								■					
DRAM								■					
When Outputs	5 years							■					■

2.5.4 Spatial Techniques

It appears, although there is a trivial change of modeling techniques and its associated processes, major revolution can be seen in terms of spatial techniques and user interfaces. GIS, geographical information system, can be noticed as the most popular spatial technique involved with transport-land use models. Some transport-land use models, which have not been developed with GIS originally, came up later as a new edition with the integration of GIS. Main rationale behind this is that GIS is not a dominant system that is only capable of visualizing and understanding geographic data to reveal relationships, patterns and trends, but also it allows users to question, analyze and interpret them. As per the available literatures, other than the DELTA, MEPLAN and PTOLEMY, all other models reviewed here use GIS. But it appears the PTOLEMY is equipped with relevant spatial techniques. The STRADA has upgraded the ease of conversion between the GIS and the STRADA data format.

In URBANSIM, outputs are created also at the grid cell level, and also summarized by traffic zones and for the regions as a whole, besides outputs are written in a standard format for ease of loading into Arc View, Excel, or other common desktop tools. Graphics modules are available with ITLUP to produce maps and networks. Further, ITLUP has some versions like TELUM, etc., which use GIS. Except the GIS, The latest versions of TRANUS consist of advantages of newly software, especially word processors, spreadsheets and traffic models. GIS based techniques are used here to disaggregate zonal data to raster cells in order to bridge the data gap between zones and raster cells.

Some examples can be demonstrated that lack of GIS is a key obstacle to the well-being of a transport-land use model. MEPLAN is a transport-land use model of such. SPARTACUS (System for Planning and Research in Towns and Cities for Urban Sustainability), which is based on MEPLAN, is a European project undertaken to analyze the implications of urban land use and transportation policies. Here, what is new with SPATACUS other than the MEPLAN is the integration of GIS raster module to process many of the outputs of MEPLAN and calculate and display micro-scale indicators.

It is remarkable that CAST has made use of JAVA and Java3D programming languages in order to meet the spatial requirements and further CAST generates a three-dimensional view of output attributes. The user can also supplement the GIS input by adding any of the 22 cell types using a manual input facility of CAST.

Table 2.4: Spatial Techniques

Spatial Technique	GIS
URBANSIM	✓
METROSIM	✓
CAST	✓
DELTA	
MEPLAN	
PTOLEMY	
ITLUP	✓
TRANUS	✓
POLIS	✓
ILUMASS	✓
TRANSPLAN	

2.5.5 User Interfaces

User interface of a model is the first vista that user will interact. Usually, for users, interface is almost the model. Therefore, powerful interface is a significant factor to declare the soundness of a particular model. Although there are little discussions on user interfaces in literatures, available literatures follow a number of aspects namely whether it is open source, its availability for scrutiny and to further extension and adaptation to emerging requirements in modeling, ability for users to input different scenarios comprised with development policies and also to input specifications for outputs and, finally the capability for deciding specific simulation years for which to generate the outputs mostly, it appears.

The interface of URBANSIM is built upon using the open source approach to provide free access to the source code while having all above mentioned aspects are at a good enough level. The CAST's interface allows for adding global actions such as the state of the world economy, in-wars and out-wards population, planning policies, etc. to influence the actions on cells, if there is a necessity. It is remarkable that the interface of PTOLEMY has provided the room to interact with other city models such as SATURN, etc. Further, PTOLEMY's interface uniquely allows testing strategic land use and transporting policy issues, because of its wide geographic coverage and comprehensive representation of the land use and transport responses to policy interventions. The STRADA model uses the ArcView based GIS interface to interact with users and to generate outputs in more meaningful ways.

Moreover, the interface of TRANUS is equipped with object oriented graphical interface called TRANUS User Cell (TUS) that facilitates like setting up a database, importing and exporting data to and from other applications, running the models, presenting maps with data and results of the simulations and producing numeric reports and apply to any scale from detailed urban level to regional and national level models. Other than that, TRANSPLAN has the interface developed through VB.

2.5.6 Conclusion

Not surprisingly, these land use-transport models use many and wide variety of land use and transport related data as depicted above. But, it can be said all these models are also backed by same amount of data from the sectors like economic, environmental, and demographic and also from proposed plans and development policies. According to the literature on hand, in TRANUS and ILUMASS use several input data that are found through surveys carried out in the study region. Moreover, TRANUS is capable of calibrating the modeling process using small sample surveys to result the reliable data. No trace can be found on whether other models carry the surveys and how it is done. Some of above models were built upon the existing models such as DELTA from START, MEPLAN based on Lowry Model, ITLUP based on Lowry Model, EMPAL, and DRAM. The TRANUS model is also related to the work of Leontief on input-output accounting frame work. MEPLAN has included the classic bid-rent theory and fundamental concepts of mono centric theory to the modeling process.

Further, several models have followed the commonly known approaches and concepts for their modeling process as a whole or for a part. STRADA, URBANSIM and

DELTA use the disaggregate approach. Notable feature is that both STRADA and DELTA still use aggregate techniques for a part of modeling process, while discrete choice is followed by METROSIM, STRADA and TRANUS. In contrast to the most existing models, the CAST model employs the ideas of complexity and is developed upon cellular automata approaches with the aim of capturing the key process in the city and ILUMASS aims at embedding a microscopic dynamic simulation model of urban traffic flows into a comprehensive model system. Another interesting point is that some of above models use several sub models within the main model; URBANSIM, DELTA, PTOLEMY, STRADA and ITLUP are such models. Both URBANSIM and CAST uses cells to input and output data. In addition, modeling process of METROSIM and PTOLEMY are capable of dealing with other similar models.

With respect to operation time, three groups can be distinguished. One group of models release outputs in short term only, while next group of models generate outputs merely in long term and final group of models can generate outcomes in both short term and long term. According to the literature available, URBANSIM and DELTA belong to the former category. METROSIM and ITLUP can do long term predictions only. The final group consists with only TRANUS. Relevant literature could not be found to declare such details about other models.

Basic findings of all these models are impacts of transport on land use and vice versa and its related information, though it comes out with different names. But, ITLUP also produces air pollution information also. Features of GIS have been used in URBANSIM, CAST, ITLUP and ILUMASS, while it is said in literature that PTOLEMY also uses spatial techniques. There is no enough literature to say about such on other models. Other than that, CAST also makes use of Java and Java3D for the design purpose of the model. Further, most striking interactive features are available in the URBANSIM, CAST and TRANUS. Another interesting feature is that the interface of URBANSIM is built upon using open source approach to provide free access to the source code, and to make model more open to scrutiny and to further extension and adaptation to emerging requirements for modeling.

In overall, it seems that all models can do a major part of decision making in transport planning and its allied disciplines. Further, most recent models have followed the prospects and eliminated the constraints in nearly all past land use and transport models. Thus, existing models provides an excellent background for new developers. Also, present day models are created with conspicuous interactive features allowing user to add and amend the number of inputs and their significance to the model. Using GIS is present day models has paved the way for input or output the spatial related data, which are more explicable than normal numeric or written data. Some advance models can also be used at no cost.

Most models were developed based on one city or one country. Also, other than the TRANSPLAN, all other models are from developed countries. It can be widely observed that there is a huge difference in terms of travel conditions, travel behavior, other travel related parameters, land uses, data availability, investment capacities, etc. Therefore still there is a doubtful situation that how much accuracy will be there in applying to other cities. Although, TRANSPLAN was built for Sri Lankan conditions, lacking of features and spatial integration has limited the use of TRANSPLAN by now. Further, it can be seen that most models have neglected the social aspect in details and changing preferences of living beings. Finally, it can be concluded, there is a huge necessity of land use and transport models for developing countries at their nature.

CHAPTER 03: SELECTION OF MODEL PARAMETERS

3.1 Introduction

Transportation networks are complex, large-scale systems, and come in a variety of forms, such as road, rail, air, and waterway networks. Transportation networks provide the foundation for the functioning of our economies and societies through the movement of people, goods, and services. From an economic perspective, the supply in such networks is represented by the underlying network topology and the cost characteristics whereas the demand is represented by the users of the transportation system (Nagurney, 2007). Prevailing complex situation forced scholars to go for mathematical modeling initially. Beckmann, McGuire and Winsten (1956) were the first to rigorously formulate these conditions mathematically. Their approach made the formulation, analysis, and subsequent computation of solutions to transport network problems based on actual transportation networks realizable. Since then, a vast improvement was occurred in the transport modeling aspect. Improvements for modeling techniques have gained a substantial attention over the last decades. Finding an appropriate modeling technique, which consumes less number of inputs, to output desired decisions is the main decision that should be taken prior to any sort of model development in the transportation field (Litman, 2005). With the introduction of digital computers, a beginning to think about the "User Friendliness" in transport and, transport and land use models were emerged deviating from mathematical models only. Later, in 1990s, an incorporation of mathematical models into a Geographical Information System (GIS) has improved vastly matters by streamlining data input and providing better interpretation of model outputs (Pullar and Springer, 2000).

Although much progress could be observed, what is particularly important is that many of earlier day approaches first developed in 1950s and 1960s are still highly significant 50 years on, and are a part of a new impetus in land use-transport modeling (Guhathakurta, 2003). It can be noted that different scholars attempted and are attempting differently to perform the travel demand estimation.

Finding an appropriate modeling technique can be considered as the initial task in a transport and land use model development. But, it cannot be done individually as the selected modeling technique needs to output desired outputs and certain inputs may be required to run the modeling technique. Therefore, cross-checking should be performed simultaneously. Suitable spatial technique and interfaces can be selected later.

3.2 Transport and Land Use Aspects in Sri Lanka

Prior to selecting an appropriate modeling technique and, its input and output parameters, a careful investigation of transportation and land use aspects in relevant to Sri Lanka and the present decision making process needs to be carried out.

Although many scholars argue the need of better integration of transport and land use in Sri Lanka, still no clear attempt has been made to integrate both these aspects. In Sri Lanka, still transport planning and land use planning are mainly done by two separate authorities called Road Development Authority (RDA) and Urban Development Authority (UDA) respectively. Although, some communications are prevailing in the means of meetings, workshops, letters, etc., those are not effective at all. Local authorities are another institutions, who have the power to carry out transport and land use planning to a certain extent under their purviews. Other than in very few instances, these local authorities never do an analysis of national level planning for their decisions. In contrast, RDA and UDA have no idea about the local authorities' decisions. National Physical Planning Department (NPPD) is responsible for the preparation of spatial and physical planning policies to Sri Lanka. Although inputs are taken from RDA, UDA and relevant other agencies at one stage, there is an extreme doubt whether those are clearly understood and the dynamic behavior of planning is tackled. Same situation can be observed in other planning authorities such as Mahaweli Authority of Sri Lanka, etc. Other than that, institutes, who are preparing economic, social and environmental plans, have very limited communications with transport and land use planning authorities despite the huge relationship exists between them. Incorrect mechanisms of predicting the future are another drawback to making policies and planning in those agencies. Here, it can be concluded that isolated decision making process and lack of coordination have been the main issues in planning authorities of Sri Lanka. Although authorities know the prevailing situation is heading for the wrong planning and lack of proper mechanisms for better coordination have kept them away from it. Other than the planning authorities, transport and land use cannot be ignored at any governing authority in Sri Lanka. Most of government authorities may require knowing the status of present and future transport and land use to take their own decisions. Further, decisions of these authorities affect to transport and land use aspect directly and indirectly.

3.3 Modeling Approaches and Techniques

As mentioned in the earlier chapter, it can be observed that many modeling techniques are available in present-day transport and land use models. Less number of models has two separate models called as macro and micro level models in order to capture the inter-level and intra-level trips respectively. Although other models have only one model, within the same model two algorithms are running to analyze inter and intra trips. Further, the different nature of the micro-level and macro-level travel behavior is well acknowledged in the literature. Therefore, to make informed transportation planning decisions on macro level or micro level, planners and engineers have to be able to predict travel characteristics and usage of transport services under different socio-economic scenarios, transport services and land use configurations comparing other level travel demand estimations.

In Sri Lankan context, it appears and this dissimilarity is much more. Some distinctive differences can be noticed here.

- In macro level, most of the trips are occurred in A and B class roads. But, all the A, B, C, D and minor roads are utilized in the micro level. This happens mainly because of visitors do not aware of local roads.
- Micro level travels are happening in a high number comparing to the macro level.
- Mostly, short time and distance trips are taking place in micro level.
- Micro level trips are happening at greater extent on roads only.

- It is very hard to characterize the micro-level trips as those are mostly not planned and are happening in the irregular patterns.

Further, expected amount of details for decision making for micro-level planning are higher over the macro-level planning. Moreover, a slight deviation of accurate information for decision making for micro-level will make most terrible decisions that will badly affect to the well-being of the city or the locality. Therefore, accurate outputs are the highest concern for micro level transport planning.

The macro models in most of the occasions take large geographical areas as the traffic analyzing zones and also consider only main roads as the transportation network. This happens mainly due to that macro-models are prepared for areas that comprises with large geographical areas such as states or countries, which are governed by the central government. Main objectives behind the macro model are to prepare and evaluate policies, and identify and evaluate mega infrastructure projects. Thus, it is not needed to analyze the minor data such as household data, use of local road, etc., where it is not practical to collect them and integrate into the macro-models also.

Due to present dissimilarity exists in Sri Lanka in terms of the travel behavior, decision making process, data availability, etc. two separate models are required to do the analysis for macro level and micro level. Therefore, two appropriate modeling techniques are required here to model the macro and micro levels separately.

3.4 Modeling Approaches

3.4.1 Unified vs. Composite

With respect to overall model structures, two groups can be distinguished. One group of models searches for a unifying principle for modeling and linking all subsystems; the others see the city as a hierarchical system of interconnected but structurally autonomous subsystems; the resulting model structure is either tightly integrated, ‘all of one kind’, or consists of loosely coupled sub models, each of which has its own independent internal structure. The former type of model is called ‘unified’, the latter ‘composite’ (Wegener et al, 1986).

Unified modeling technique mostly requires a less number of information as using one definite approach, which was made as an algorithm developed from the regression analysis. Such models can be calibrated from the census data and analyzed census data. Composite modeling goes a step further and allows analysts to systematically combine two or more forecasts (Fullerton, 1989). The requirement of more information in diverse aspects is the major limitation in the composite modeling technique. Involving more information would generate more accurate outputs, but cost and time will be more.

Some unified models are recursive models, which are quasi-dynamic. They model the development of a city over time, within one simulation period they are in fact cross-sectional. Composite models consist of several interlinked sub models that are processed sequentially or iteratively once or several times during a simulation period. This makes composite models well suited for taking account of time lags or delays due to the complex superposition of slow and fast processes of urban development (Wegener et al., 1986)

Taking the accuracy, data requirements, time and cost factors, a macro model is more valid with the unified approach while, a composite approach should be used for the micro modeling.

Use of sub models, one's outputs are taken as one's inputs, also can be considered as the composite approach.

Table 3.1: Comparison between Unified and Composite Approaches

Aspect	**Unified Approach**	**Composite Approach**
Complexity	Low	Low
Data requirement	Low	High
Data collectivity	Easy	Moderate
Accuracy	Moderate	High
Validation	Easy	Easy
Cost	Moderate	High

As mentioned earlier, outputs of micro model should be more accurate as even a slight deviation would affect to the results. Comparing to all aspects, the unified approach is more appropriate for the macro model while the composite approach is compulsory with the accuracy level although some data need to be collected.

3.4.2 Equilibrium vs. Disequilibrium

Relationships between transport supply and demand continually change, but they are mutually interrelated. It can be observed that concepts of equilibrium and disequilibrium are more economic related. From a conventional economic perspective, transport supply and demand interact until an equilibrium is reached between the quantity of transportation the market is willing to use at a given price and the quantity being supplied for that price level (Sabharwal, 2013). Since urban areas do not really ever reach a general equilibrium in land and travel markets, the disequilibrium structure will likely to be adopted in many future attempts to model land markets (Lacono, Levinson and El-Geneidy). The disequilibrium of demand for and supply of transport need to be analyzed so that mean has to be found out for correcting that disequilibrium (Sabharwal, 2013).

Table 3.2: Comparison between Equilibrium and Disequilibrium Approaches

Aspect	**Equilibrium Approach**	**Disequilibrium Approach**
Complexity	High	High
Data requirement	High	High
Data collectivity	Low	High
Accuracy	Low	High
Validation	Moderate	Moderate
Cost	Moderate	High

Although more data collection needs to be done, adopting the real scenarios, the disequilibrium approach is more valid here.

3.4.3 Aggregate vs. Disaggregate

An aggregate concept uses the data in zonal levels and in contrast the disaggregate concept uses the data in household level and individual person level. Aggregate and disaggregate travel demand models are viewed by transportation planners as mutually exclusive or competitive approaches to the forecasting problem (MeFadden and Reid, 1975). Most of earlier travel demand models were to predict the aggregate travel demand for long-term socio economic scenarios, transport capacity characteristics and land use configurations (Pinjari and Bhat).

In a traditional trip-based model, aggregate estimates of demand are predicted first. Then each subsequent step in the model system further disaggregates the overall aggregate estimates of demand. In contrast, in an activity based model system, disaggregate estimates of demand are predicted first, and then these estimates are aggregated by geography, time of day, and market segment for input in the network assignment model. Producing disaggregate estimates of demand helps to reduce the bias in the estimates of demand and provide greater flexibility to analyze the impacts of policies and investments. However, the use of this disaggregate data must be informed by the analysis context. Although, disaggregate approach estimates the demand at detailed spatial and temporal resolutions for many market segments, the accuracy of these estimates at fine levels of disaggregation should be carefully considered in application (TRB, 2015). The disaggregate approach is very data intensive and lots of surveys should be done, while the aggregate approach could be done mostly by census data.

The mainstream trend in urban transport and land use modeling is disaggregation (Wegener, 2011). With growing individualization of society, urban life styles and hence mobility and location patterns and social networks are becoming more diversified, and disaggregate models are better able to capture this heterogeneity. Although the accuracy is high, only very few microscopic urban travel and land use models have become operational. There are practical reasons for this: the data requirements and computing times of these models tend to be enormous.

Table 3.3: Comparison between Aggregate and Disaggregate Approaches

Aspect	**Aggregate Approach**	**Disaggregate Approach**
Complexity	Low	Moderate
Data requirement	Low	High
Data collectivity	Easy	Hard
Accuracy	Moderate	High
Validation	Easy	Moderate
Cost	Low	High

Comparing all these, the aggregate approach is more appropriate for the macro model and the disaggregate approach is much needed for the micro level.

3.4.4 Static vs. Dynamic

The static models, by their very nature, cannot realistically capture urban spatial processes and their effects on the transport system (Sivakumar, 2007). Static transport and land use models treat land use and transport systems as being exogenous to each other. Nevertheless, some static models continue to be used this day, either as a means of adding a land use dimension to existing models without undertaking the extra work needed to create a dynamic model, or because the static model represents an equilibrium state which is of interest in itself (Sivakumar, 2007). The earliest transport and land use models that attempted to capture the interactions between the land use and transport systems were essentially static models, driven typically by gravity formulations or input-output formulations (Lowry, 1964). These early models are not very responsive to policy analyzes (Sivakumar, 2007). Dynamic models, on the other hand, are based on the assumption that some changes, e.g. changes in demand, are faster than others, e.g. responses of supply, and that these differences in speed of adjustment are so large that urban systems are normally in disequilibrium (Sabharwal, 2013). The discussion on dynamic is related to the issue of equilibrium. Equilibrium models are based on the assumption that interdependent model variables, such as process, supply and demand, adjust to equilibrium with zero delay or, if adjustment is delayed, equilibrium is eventually reached.

Table 3.4: Comparison between Static and Dynamic Approaches

Aspect	Static Approach	Dynamic Approach
Complexity	Low	High
Data requirement	Low	High
Data collectivity	Low	High
Accuracy	Low	High
Validation	Moderate	High
Cost	Moderate	High

Taking the accuracy as the highest concerning factor, the dynamic approach is the suitable technique for the micro model. Valuing the cost and effort need to be done, the static approach is more valid for the macro model.

3.5 Existing Modeling Techniques

Presently, many transport and land use models developed through diverse types of modeling techniques are in operation throughout the world. In order to find out the most suitable modeling techniques, an in-depth analysis was carried out of present modeling techniques.

3.5.1 Economic Based Modeling Techniques

Transport demand is generated by the economy, which is composed persons, institutions and industries and which generates movements of people and freight (Sabharwal, 2013). All economic structures are being built based on top of the land. Land is the most basic of all economic resources, fundamental to the form that economic development takes (Stilwell and Jordan, 2004). Land use change is not only the consequence of economic growth but also its direct and indirect driver. Thus, prevailing complex interaction between transportation and land use has made a huge inter-relationship between transport and economy. Further, transportation does a main role in meeting-up the producers, suppliers and consumers. Due to the strong relationship between land use and economy, thus transport and economy, most scholars have tried to predict the transport demand through different economic means. Both classic and modern theories in economics have been used for this.

3.5.1.1 Bid Rent Theory

The bid rent theory, primarily attributed to Alonso (1964) and Muth (1969), models the relationship between distance from the city center and house process. The theory states that rents are bid upwards close to the city center as households attempt to minimize transportation costs. Residents living close to the city center have to travel less to get to work or entertainment centers, and this decreases disutility. Conversely, rents are lower away from the city center because transportation costs for residents there are high. Rent values give an important indication of the accessibility and vice-versa (Penn, 2011).

Accessibility argued, becomes an important matter of scale in order to understand how economic actions are materialized in urban space and how space affects socio-economic interactions at the local design scale of the city (Narvaez, Penn and Griffiths, 2013). Properties of this relationship are investigated through rent values of different real estate property markets in the city of Cardiff, UK (Narvaez, Penn and Griffiths, 2013). According to Pacione (2005) "many of the CBD or city centers, in the US and the UK, have been transformed by their social and economic processes, such as deindustrialization, retail activities, decentralization of population, increased socio-spatial polarization and reduced accessibility due to the increasing demand for car ownership". In this sense, cities are the production of social and economic processes in which the concentration of activities and diversity of uses becomes part of a self-organizing economy in the city.

Therefore, an application of bid rent theory is very important for a transport and land use model, which has the capability of predicting both land use and travel changes.

3.5.1.2 Microeconomic Theory

The relationships between transportation and the economy are very complex and poorly understood (NAP, 2002). Further, Zhang (2004) mentions that land use, economic development, and transportation are deeply interrelated. Indexes of accessibility, impedance, bottlenecks and congestion may have great value, and these features are closely tied to the economic impact of transportation (NAP, 2002).

Existing economic theories, both macroeconomic and microeconomic, are doing a great job to characterize the complexity of the transport and land use integration.

As the terms imply, microeconomics focuses on micro or small segment of economy and it studies the decision making process and economic problems of individuals (household, firm, industry, etc.) in an economy with respect to that how they use scare means or resources at their disposal for satisfying their unlimited ends. The models, which evolved from this microeconomic approach, were started by adopting the conceptual framework of classical and neo-classical economics (Barra, 1989). In this approach, the location of activities is seen as the outcome of a combined market mechanism involving three basic elements: commodities, land and transport. Theories so called the theory of consumer behavior, theory of production and costs, theory of factor pricing, and theory of economic welfare are covered under the microeconomic (BCS).

Further, because of its intensive use of infrastructures, the transport sector is an important component of the economy and a common tool used for development (Rodriguez and Notteboom, 2016). Word experiences show that the emergence of economic infrastructures such as airports, sea ports, etc. changes the urban structure at a greater extent. Further, rising car ownership, income growth and the declining real cost of using cars have been identified as the key factors that have shaped person travel around the world (Paulley, Balcombe et al. 2006). Dargay (2007) argues that all above three factors are economic factors. Moreover, Hanson (1982), Cervero (1996), McLeod (1989) and Naess (1993) say that with the increase of household income, thus increases the car ownership also, the trip frequency, travel distance, proportion of car journey and transport energy consumption are also increased.

3.5.1.3 Input-Output Accounting Framework (Leontief)

Input-output accounting framework is yet another economic theory applied in most transport and land use models. The main objective of the well-known input-output model, developed by Leontief in the late 1930s, is to study the interdependence among the different sectors in any economy (Miller and Blair, 1985). This tool holds upon a very simple, yet essential notion, according to which the output is obtained through the consumption of production factors (inputs) which can be, in their turn, the output of other industries. Hence, one of the principal tasks of input-output analysis is to identify the indirect demands concerning the intermediate consumptions necessary to generate the outputs. Here, input and output table gives a quite complete picture of the economy at some specific point in time, providing estimates for an important set of macroeconomic aggregates (production, demand components, value added and trade flows) and disaggregating these among the different industries and products (Sargento, 2009).

Understanding the future economic hotspots is very important for taking decisions to reshape the urban structure in the way it is beneficial to living beings of the community. It can be observed that although the bid-rent theory cannot be used as a main modelling technique, it is very important to be used as a sub model to generate the outputs such as land rents, economic hotspots, sub city centers, transportation cost, etc.

3.5.1.4 Mono-Centric Theory

The mono-centric theory works according to the bid-rent theory and both theories were developed by Alonso. Since its formulation in 1964, Alonso's mono-centric city model of a disc-shaped Central Business District (CBD) and surrounding residential region has served as a starting point for urban economic analysis. Mono-centricity has weakened over time because of changes in technology, particularly, faster and cheaper transportation (which makes it possible for commuters to live farther from their jobs in CBD) and communications. Arguing that the mono-centric assumption of employment concentrated in the CBD no longer reflects the patterns of contemporary urban areas, other researchers have examined the use of distances to multiple employment centers to predict population and employment densities and later, land values and housing prices (Ottensmanna, Paytona and Manb, 2008).

3.5.1.5 Random Utility Theory

Random utility theory is widely used today in the transport and land use modeling. Random utility theory models an agent's preferences on alternatives by drawing a real-valued score on each alternative (typically independently) from a parameterized distribution and then ranking the alternatives according to scores (Soufiani, Parkes and Xia). Behavioral models derived from the random utility theory, which is the richest and by far the most widely used theoretical paradigm for modeling transport-related choices and generally, choices among discrete alternatives (Cascetta, 2009). Random utility theory is based on the hypothesis that every individual is a rational decision-maker, maximizing utility relative to his or her choices (Cascetta, 2009). Applying random utility theory has some shortcomings also. Often, due to data or computational constraints, the analyst must use aggregated alternatives to estimate the model. These aggregates are defined by averaging characteristics of alternatives over pre-specified groups. Parsons, Kealy and Mary (1992) demonstrate that unless some very restrictive conditions hold, the use of aggregated alternatives will lead to biased results. Further, they mention that when the number gets too large, say in the hundreds, estimation becomes burdensome.

3.5.2 Other Modeling Techniques

3.5.2.1 Cellular Automata

Cellular Automata (CA) have emerged in the last few years as a very promising alternative to existing traffic flow models (Benjaafar, Dooley & Setyawan). CA is characterized as an artificial life approach to simulation modeling (Levy, 1992) and is name after the principle of automata (entities) occupying cells according to localized neighborhood rules of occupancy. CA are mathematical idealizations of physical systems in which space and time are discrete, and physical quantities take on a finite set of discrete values. A cellular automaton consists of a regular uniform lattice, usually finite in extent, with discrete variables occupying the various sites. The state of a cellular automation is completely specified by the values of the variables at each site. The variables at each site are updated simultaneously, based on the values of the variables in their neighborhood at the preceding time step, and according to a definite set of "local rule". Performance metrics are generally obtained through computer simulation of the evolution of the cellular automata on over time.

In order to implement the CA concept, the required amount of data such as detailed land use maps, satellite maps, etc. is very high. In making a model for whole Sri Lanka, applications of CA concepts are far more beyond the reality. Although the data can be prepared for the micro level, several problems can be distinguished. As micro level does not limit to an isolated geographical area, there is an extreme problematic situation to find the affection from outside areas. Taking the external effects is a problem here. Therefore, applying the CA concept to the Sri Lankan situation would generate more issues.

3.5.2.2 Mathematical Models

Many scholars (Beckmann, McGuire, Winsten, et al. Dafermos and Sparrow) take all transport models and, transport and land use models as mathematical models. The equilibrium link and path flows could only be obtained as the solution of a mathematical programming problem (Nagurney). Although, mathematical models of dynamic behavior are also based on empirical surveys and observations, strictly speaking, the results of mathematical models are no more universally valid than those of empirical studies but are only valid for situations, which are similar to those for which of their parameters were estimated (Spiekermann). Nevertheless it is possible to transfer the dynamic behavior in the transport and land use modeling to mathematical modeling within certain limits to still unknown situations. In addition, mathematical models are the only method by which the effects of individual determining factors can be analyzed by keeping all other factors fixed.

3.5.2.3 Microsimulation

Microsimulation is a general term for modeling the behavior and interactions of micro units such as persons, households, firms, etc. (Sutherland, 2012). There is a great potential for useful application of microsimulation models to the analysis of complex traffic problems in urban areas, alongside the analytical techniques that are in use today. Microsimulation is useful due to increasing levels of system complexity and uncertainty involved in the operation of urban traffic networks (Akcelik et al., 2001). Traffic microsimulation models are quickly becoming the defacto standard for the evaluation and development of road traffic management and control systems worldwide. Traffic simulation computer models capture the interactions of real world road traffic through a series of complex algorithms describing car following, lane changing, gap acceptance, and spatial collision detection. In addition, free form pedestrian movement is replicated using agent based spatially aware models allowing road traffic to interact with pedestrians as they do in the real world.

Pitfalls exist in simulation as in every human attempt to abstract and idealize (Algers et al., 2000; Fox, 2000). Further, while saturation flow and lost time for signalized intersections are the most widely used parameters in traffic engineering practice, and are employed by analytical models extensively, microsimulation models generally ignore them, as in the case of capacity parameter (Akcelik et al., 2001).

3.5.2.4 Microscopic Dynamic Simulation

There is no much clear difference between micro-simulation models and microscopic models, but microscopic models depend extensively on car following models (Al-Qadi, 2008). The rationale is to utilize observed distributions (e.g. acceleration/ deceleration distributions) to predict the driver's behavior (selection of inter-spacing from the leading car, acceleration, deceleration, etc.) in response to a specific stimulus. Car following models are very effective, especially, in modeling traffic in a confounded space (e.g. single lane traffic) where the driver actions become limited (Al-Qadi, 2008). Car following models commonly utilize three functions to describe the perception of the driver to a specific stimulus, the decision making process in response to stimuli, and the final control or reaction by the driver. Car following models differ in their representation of the final control-stimulus function. No systematic validation procedure for microscopic traffic simulation has been commonly accepted and performed in the past although more and more people have realized its importance (Hawas, 2002). Use of aggregate data for the validation has several shortcomings: it lacks a microscopic element and averages alone are not sufficient to validate the model, and there are needs to look at the distribution of the variables over time and space.

3.5.2.5 Entropy Maximization

The first use of entropy-maximizing models in geography was by Alan Wilson, in research on transportation planning (Wilson, 1970). Before his work, most researches had applied the gravity model based on an analogy with Newton's theory of interaction between two bodies separated by the distance (Johnston and Pattie). A form of ecological inference developed and applied by human geographers is entropy-maximizing. Entropy – a concept developed in thermodynamics but since widely applied in information theory – is a measure of the amount of uncertainty in a probability distribution, subject to constraints. Entropy is linked to another important mathematical and statistical concept – maximum – likelihood. In the study of probabilities, the maximum-likelihood estimate is that most likely to occur.

Entropy maximization approach has been widely used in transportation planning (Wang, Yao and Jing). Entropy maximization concept has been widely applied in vast range of transport and land use models such as production-constrained models, attraction constrained models, production-attraction-constrained models, models for transportation by different modes and models for transportation via intermediate points (Kapur, 2006). Preparation of the origin-destination (O-D) can be seen as the major transportation application, which is being developed and researched using the entropy maximization. Wilson was the first to estimate O-D flows with entropy maximization technique (Wilson, 1970). Lately, some studies which applied the entropy-maximizing approach to estimate O-D matrix could also be specified (Zuylen and Willumsen, 1980; Spiess 1987; Yu and Lee 2002; Cis et al. 2002).

It is well proved that entropy maximization technique can generate new models under suitable constraints. Second, the entropy method is ascertained in view of the maximum information theory. Third, by comparing the accuracy of depicting the issues and the complexity of calibrating parameters among a variety of entropy models, the recommended model, which is selected as the practical one that is easy to be calibrated and precise, is given to be applied in practice.

3.5.2.6 Real Estate Market

The real estate market can also be called as the land market. The existence of highways, sewer services and other public facilities influences the behavior of both suppliers and demanders of residential and commercial properties (Damm et al.). The benefits of these facilities and services are, at least in theory, partially or wholly capitalized into urban property values. The level of market regulations when modeling land use changes can be varied between a regulated land use planning system to a free market (Bok and Zondag). A land and real estate connection simulates supply constraints based on the inputs of available land, land use policies, projected construction, and different levels of government influence, ranging from completely regulated to free market policies (Bok and Zondag). Changes of land uses are visible according to the real estate market thus changing the travel behavior of the particular locality. Therefore, the real estate market has been used as a technique to model the travel behavior.

3.6 Analysis of Modeling Techniques

Table 3.5: Analysis of Modeling Techniques

Modeling Technique	Complex	Data Requirement	Data Collectivity	Accuracy	Validation Process	Cost
Cellular Automata	Very High	Very High	Very High	Moderate	Hard	Very High
Mathematical model	Low	Moderate	Moderate	Moderate	Easy	Moderate
Microsimulation	High	High	High	High	Moderate	High
Microscopic dynamic simulation	Very High	Very High	Very High	High	Hard	Very High
Entropy maximization	Very High	Very High	High	Moderate	Hard	High
Real estate market	High	Very High	High	Moderate	Hard	High
Bid rent theory	Moderate	High	High	Low	Hard	High
Input-output accounting framework	Moderate	High	High	Low	Hard	High
Mono-centric theory	Moderate	High	High	Low	Hard	High
Random utility theory	Moderate	High	High	High	Moderate	High

As per the accuracy, the microscopic dynamic simulation is the most appropriate modeling technique for making the models. But due the high complexity, high data requirements, complex validation process and difficulty of collecting the required data, implementing the microscopic modeling technique is a huge challenge. Therefore, the microsimulation and random utility theory modeling techniques are more valid for the micro model as the geographical area is small. As per the literature on hand, the microsimulation technique is more sophisticated as it covers wider area (the random utility theory covers mostly the economic aspect) and the essence of random utility theory can be easily incorporated into the microsimulation approach if required. But, the microsimulation approach is not appropriate for the macro modeling as it is not practical for collecting the huge bundle of data covering the whole Sri Lanka. As a result, the mathematical modeling is the most practical solution here, but, so many arguments are prevailing such as the type of the mathematical modeling, input parameters and output parameters.

3.7 Analysis of Input Parameters

Table 3.6: Analysis of Input Parameters

Parameter Type	Data Type	Data	Percentage by No. of Models Used	Used in Micro/ Macro Model	Comments
Input Parameter 1	**Census Data**	Birth and Death Rates	91%	Macro Model	**Available/** Need to Adjust/Need to Collect/ Not Available **Not Expensive**/ Expensive **Practical**/ Not Practical
		Population data	100%	Macro Model	**Available/** Need to Adjust/Need to Collect/ Not Available **Not Expensive**/ Expensive **Practical**/ Not Practical
		Immigration data and emigration data	46%	Macro Model	**Available/ Need to Adjust**/Need to Collect/ Not Available **Not Expensive**/ Expensive **Practical**/ Not Practical

Parameter Type	Data Type	Data	Percentage by No. of Models Used	Used in Micro/ Macro Model	Comments
		Number of households	82%	Macro Model / Micro Model	**Available**/ Need to Adjust/Need to Collect/ Not Available **Not Expensive**/ Expensive **Practical**/ Not Practical
		Household Income and Size	55%	Macro Model	**Available**/ **Need to Adjust**/ **Need to Collect**/ Not Available **Not Expensive**/ Expensive **Practical**/ Not Practical
		Age of the head	27%	Micro Model	Available/ Need to Adjust/ **Need to Collect**/ Not Available Not Expensive/ **Expensive** Practical/ **Not Practical**
		Number of Children	27%	Micro Model	**Available**/ Need to Adjust/Need to Collect/ Not Available **Not Expensive**/ Expensive **Practical**/ Not Practical
		Number of Workers	27%	Macro Model / Micro Model	**Available**/ **Need to Adjust**/Need to Collect/ Not Available **Not Expensive**/ Expensive **Practical**/ Not Practical
		Schools and Universities Data	9%	Macro Model	**Available**/ Need to Adjust/Need to Collect/ Not Available **Not Expensive**/ Expensive **Practical**/ Not Practical
	Analyzed Census Data	Population change	55%	Macro Model / Micro Model	**Available**/ **Need to Adjust**/Need to Collect/ Not Available **Not Expensive**/ Expensive **Practical**/ Not Practical
		Educational skills	55%	Macro Model	Available/ Need to Adjust/ **Need to Collect**/ Not Available Not Expensive/ **Expensive** Practical/ **Not Practical**

Parameter Type	Data Type	Data	Percentage by No. of Models Used	Used in Micro/ Macro Model	Comments
		Household change and movement	55%	Micro Model	Available/ Need to Adjust/ **Need to Collect**/ Not Available Not Expensive/ **Expensive** Practical/ **Not Practical**
Input Parameter 2	**Transport Data**	Travel Time and Cost	64%	Macro Model / Micro Model	Available/ Need to Adjust/ **Need to Collect**/ Not Available Not Expensive/ **Expensive** **Practical**/ Not Practical
		Number of Trips	64%	Macro Model / Micro Model	Available/ Need to Adjust/ **Need to Collect**/ Not Available Not Expensive/ **Expensive** **Practical/** Not Practical
		Road Network Data (Road Length/ Width, Roughness, Curvature, Median Width, Availability of Shoulders, etc.)	72%	Macro Model / Micro Model	Available/ Need to Adjust/ **Need to Collect**/ Not Available Not Expensive/ **Expensive** **Practical**/ Not Practical
		Parking Data	18%	Micro Model	Available/ Need to Adjust/Need to Collect/ **Not Available** Not Expensive/ **Expensive** Practical/ **Not Practical**
		Car Ownership Data	27%	Macro Model	**Available/ Need to Adjust**/Need to Collect/ Not Available Not Expensive/ **Expensive** **Practical**/ Not Practical

Parameter Type	Data Type	Data	Percentage by No. of Models Used	Used in Micro/ Macro Model	Comments
		Congestion pricing	18%	Micro Model	Available/ Need to Adjust/**Need to Collect**/ Not Available Not Expensive/ **Expensive** Practical/ **Not Practical**
		Fares	9%	Micro Model	Available/ Need to Adjust/**Need to Collect/** Not Available Not Expensive/ **Expensive** Practical/ **Not Practical**
		Preferences	9%	Macro Model / Micro Model	Available/ Need to Adjust/**Need to Collect/** Not Available Not Expensive/ **Expensive** **Practical**/ Not Practical
		Operational Costs	9%	Macro Model / Micro Model	Available/ Need to Adjust/**Need to Collect**/ Not Available Not Expensive/ **Expensive** **Practical**/ Not Practical
		Service Levels	9%	Macro Model / Micro Model	Available/ Need to Adjust/**Need to Collect**/ Not Available Not Expensive/ **Expensive** **Practical**/ Not Practical
Input Parameter 3	**Employment Data**	Job Assignment Data	73%	Macro Model	**Available**/ **Need to Adjust**/Need to Collect/ Not Available Not Expensive/ **Expensive** **Practical**/ Not Practical
		Labor Details	73%	Macro Model	**Available**/ **Need to Adjust**/Need to Collect/ Not Available **Not Expensive**/ Expensive **Practical**/ Not Practical
		Job Sectors	9%	Macro Model	**Available**/ **Need to Adjust**/Need to Collect/ Not Available **Not Expensive**/ Expensive **Practical**/ Not Practical

Parameter Type	Data Type	Data	Percentage by No. of Models Used	Used in Micro/ Macro Model	Comments
		Job Salaries	9%	Macro Model	Available/ Need to Adjust/**Need to Collect**/ Not Available Not Expensive/ **Expensive** **Practical**/ Not Practical
Input Parameter 4	**Land Use Data**	Land Use Data	73%	Macro Model / Micro Model	**Available**/ **Need to Adjust**/Need to Collect/ Not Available Not Expensive/ **Expensive** **Practical**/ Not Practical
Input Parameter 5	**Incorporation of projects, plans and policies**	Land Use Plans	27%	Macro Model / Micro Model	**Available**/ **Need to Adjust**/Need to Collect/ Not Available **Not Expensive**/ Expensive **Practical**/ Not Practical
		Infrastructure Plans	27%	Macro Model	**Available**/ **Need to Adjust**/Need to Collect/ Not Available **Not Expensive**/ Expensive **Practical**/ Not Practical
		Urban Growth Boundaries	18%	Macro Model	**Available**/ **Need to Adjust**/Need to Collect/ Not Available **Not Expensive**/ Expensive **Practical**/ Not Practical
		Environment Sensitive Land Proposals	18%	Macro Model	**Available**/ **Need to Adjust**/Need to Collect/ Not Available **Not Expensive**/ Expensive **Practical**/ Not Practical
		Transport Plans	27%	Macro Model	**Available**/ **Need to Adjust**/Need to Collect/ Not Available **Not Expensive**/ Expensive **Practical**/ Not Practical
		Policies	36%	Macro Model	**Available**/ **Need to Adjust**/Need to Collect/ Not Available **Not Expensive**/ Expensive **Practical**/ Not Practical

Parameter Type	Data Type	Data	Percentage by No. of Models Used	Used in Micro/ Macro Model	Comments
Input Parameter 6	**Economic Data**	Expenditures of Goods and Services	27%	Macro Model	Available/ Need to Adjust/Need to Collect/ **Not Available** Not Expensive/ **Expensive** Practical/ **Not Practical**
		Inflation Data	18%	Macro Model	**Available/ Need to Adjust**/Need to Collect/ Not Available **Not Expensive**/ Expensive **Practical**/ Not Practical
		Economic Growth Scenarios	18%	Macro Model	Available/ Need to Adjust/Need to Collect/ **Not Available** Not Expensive/ **Expensive** Practical/ **Not Practical**
		Investment Details	18%	Macro Model	Available/ Need to Adjust/**Need to Collect/** Not Available Not Expensive/ **Expensive** Practical/ **Not Practical**
		Imports and Exports Details	9%	Macro Model	**Available/ Need to Adjust**/Need to Collect/ Not Available **Not Expensive**/ Expensive **Practical**/ Not Practical
		Tax Data	36%	Macro Model	Available/ Need to Adjust/**Need to Collect/** Not Available Not Expensive/ **Expensive** Practical/ **Not Practical**
Input Parameter 7	**Environmental Data**	Environmental Data	18%	Macro Model	Available/ Need to Adjust/**Need to Collect/** Not Available **Not Expensive**/ Expensive **Practical/** Not Practical
Input Parameter 8	**Real Estate Data**	Real Estate Demand Data	45%	Macro Model	Available/ Need to Adjust/Need to Collect/ **Not Available** Not Expensive/ **Expensive** Practical/ **Not Practical**

Parameter Type	Data Type	Data	Percentage by No. of Models Used	Used in Micro/ Macro Model	Comments
		Real Estate Prices	55%	Macro Model	Available/ Need to Adjust/**Need to Collect**/ Not Available Not Expensive/ **Expensive** **Practical**/ Not Practical
		Housing Markets	36%	Macro Model	Available/ Need to Adjust/**Need to Collect**/ Not Available Not Expensive/ **Expensive** **Practical**/ Not Practical
		Land Rents	36%	Macro Model	Available/ Need to Adjust/**Need to Collect**/ Not Available Not Expensive/ **Expensive** **Practical**/ Not Practical
		Land Values	18%	Macro Model	Available/ Need to Adjust/**Need to Collect**/ Not Available Not Expensive/ **Expensive** **Practical**/ Not Practical
		Business Establishment Data	9%	Macro Model	Available/ Need to Adjust/**Need to Collect**/ Not Available Not Expensive/ **Expensive** Practical/ **Not Practical**
		Residential and Non-residential Improvement Values	9%	Macro Model	Available/ Need to Adjust/Need to Collect/ **Not Available** Not Expensive/ **Expensive** Practical/ **Not Practical**
		Building Levels and Standards	18%	Macro Model	Available/ Need to Adjust/**Need to Collect**/ Not Available Not Expensive/ **Expensive** Practical/ **Not Practical**

By analyzing input parameters, the usable input data can be put into three categories as follows.

Table 3.7: Categories of Input Parameters

Available	Need to collect	Need to Estimate
Birth and death rates Population data Immigration and emigration data No of households Household income and size Number of children Number of workers Schools and universities data Job sectors Labor details Inflation data Import and export details Environmental data	Travel time and cost Number of trips Road network database Car ownership data Preferences Operational costs Service levels Job assignment data Job salaries Land use data Real estate prices Housing markets Land rents Land values	Land use plans Infrastructure plans Environmental sensitive land proposals Transport plans Policies

3.8 Output Parameters

3.8.1 Origin-Destination Matrix (OD Matrix)

In order to determine the transportation needs and appropriate solutions for an area it is important to have an understanding of the underlying characteristics of travel. The origins and destinations of traffic are among the most important of these characteristics. Therefore, OD matrix is considered as the most important aspect in the transport and land use planning. One of the most crucial requirements for the transportation planning is on arriving at the travel pattern between various zones through OD matrix estimation (Bera and Rao). OD matrixes can be effectively predicted in association with socio-economic data by different statistical means. An accurate OD matrix (both present and predicted) can then be used to generate so many outputs. Initially it outputs trip generation data, trip attraction data and trip interchange data. Later by analyzing those data, link volumes, node volumes, travel speed, travel time, congestion level, etc. Finally all these data can be used to analyze the change of industries, change of jobs and housing, population distribution, change of retail shops and many more.

3.8.2 Traffic of Routes

All decision makers related to the transport and land use planning mainly expect the number of trips in each link for each direction and, incoming and outgoing traffic in each node. These data could be used to generate the main outputs such as congestion levels of links and nodes, etc., which are really important especially for the transport decision making. Traffic volumes can be generated by both static and dynamic means. In static modeling, the volume of traffic on the link is determined directly from the loading of the origin-destination matrix to links via routes. The travel times of each link on a route are added together to determine the route travel time. This approach has some limitations as far as the realism with which it represents the actual process (taking place on the road) that gives rise to congestion and increased travel time (Chiu et al., 2011). In contrast, in dynamic models, as in reality, explicit modeling of traffic flow dynamics ensures direct linkage between travel time and congestion. If link outflow is lower than link inflow, link density (or concentration) will increase (congestion), and speed will decrease (fundamental speed-density relationship), and therefore link travel time will increase (Chiu et al., 2011). Further, according to Bottom (2011), factors such as merging two lanes into one or vice-versa, weaving (lane change maneuvers that cross over each other), meeting arterial streets (traffic signals reduce the outflow capacity of links), changing from freeways to expressways (waiting at the toll gates), etc. affect to congestion, thus to travel time. Dynamic approach requires more data on road network, travel time surveys, speed surveys, etc. Algorithms built upon empirical data can convert the static approach to dynamic approach generating more accurate outputs.

Road capacity, defined as the maximum design capacity of a given roadway at link and junction level for motorized traffic, is well understood for different lanes and carriageway widths (Roads Task Force).

3.8.3 Land Use Control

Controlling land uses needs to be done to prevent the extra traffic generation towards to existing and future transportation infrastructures at required level in order to control the congestion. New developments are one of the major causes of traffic congestion in many of the major cities of developing countries, due to the absence of adequate mitigation measures (Hokao and Mohamed). Traffic impact assessment, land use growth control, building regulations, impact fees, negotiated agreements and impact exactions are some of the means, which come as ways of land use controls. In order to make right decisions, the knowledge of future link volumes and nodes volumes are required in advance.

3.8.4 Prices and Rents of Lands

Prices and rents of lands can be taken as one of major outputs that have been generated out from existing transport and land use models. Scholars clearly have expressed that changes of transport features and adjacent land uses affect the prices of lands and vice-versa. Land use patterns and values have always tended to reflect the transportation infrastructure (Holcombe and Staley, 2001). Location within an urban area, particularly with respect to the location of employment, is assumed to be a determinant of land prices within standard urban economic models (Ottensmanna, Paytona and Manb, 2008). These are the main reasons why some transport and land use models have been built upon real estate market conditions. Private land owners have a keen interest to know the future land values of their lands well ahead so they can plan for effective use of their property. There are both positive and negative relationships. There is a negative relation between the market value of a property and the noise level emitted from the nearby freeway. Further, Giuliano claimed that “the relation between land value and freeways no longer exist because the cities are already built up and the freeway system was completed long ago”. But Giuliano’s notion cannot be accepted for the Sri Lankan situation although it is well true for well-planned cities.

3.8.5 Change of Retail Floor Space

Despite the fact that a large volume of personal travel directly or indirectly originates from retail activities, this type of trips have been largely ignored by researchers (Shobeirinejad, Burke and Sipe, 2012). Retail is considered as a major trip destination, for the non-peak hours. The need for additional retail developments in particular district centers to serve future population growth or for any significant extension to an existing district center should be identified in the development plan and be based on a significant growth in population in the intended location or on a demonstrable level of under-provision of retailing or other services to meet the regular convenience and lower order comparison shopping needs of new communities as provided for and quantified by the relevant core strategy (DECL, 2012).

It can be concluded that by knowing the change or need of retail floor space, decision makers could plot them in systematic order in the area in the way that would minimize the trips for shopping by mechanized modes substituting them with more sustainable alternatives such as walking, cycling and public transport.

3.8.6 Change of Locations of Jobs and Houses

Change of locations of jobs and changes of locations of houses are greatly inter-related. Easy accessibility to the employment places is a major reason for people to change the locations of houses (Ottensmanna, Paytona and Manb, 2008). Therefore, change of employment locations change the housing locations. Here, changing of employment places can be taken as an input to derive the new housing locations. Thus, change of locations of houses is mainly connected to the economic conditions of people. Mostly employment locations are situated in the Central Business District (CBD) and housing locations are around the CBD. Getting to know about new locations of houses in advance, relevant government authorities could allocate necessary funds for supplying required services such as water, electricity, collection of garbage, etc. and could assure these services at the right time. Economic theories are well suited for predicting the new locations of houses. Finally, change of locations of houses is closely related with the land values.

3.8.7 Change of Locations of Industries

Many important geographical factors involved in the location of individual industries are of relative significance, e.g., availability of raw materials, power resources, water, labor, markets and the transport facilities (Chand, 2015). Investors would like to establish industries most on major transportation hubs as the transportation is easy for raw materials and finished products (Wray et al., 2000). Those industries then attract people from outside area as well in the means of employment. As explained earlier, change of locations of jobs and houses are happened creating lots of impacts to the existing transportation and land use. Therefore, predicting the locations of industries is an important aspect in order to take the decisions prior for planning.

3.8.8 Population Distribution

It is a government duty to provide the necessary infrastructures especially the transportation infrastructures to the people in the country. As transportation investments are huge, required funds need to be allocated in well advance. Further, construction periods are also very long and it takes a huge time for a transportation infrastructure to become the working status since starting the construction. Therefore, predicting population distribution is really important. Land use control, land value and rent, locations of jobs and housing, etc. matter the population distribution heavily. In return, changes in population distribution alter the way of consuming the existing transportation infrastructures paving some are more congested. If the effects of transportation on population distribution and land use policy are to be properly evaluated, the subject must be defined more precisely as the role of population in transportation economics, with emphasis on the role of population as the determining transportation factor in enterprise selection and location theory (Baker).

3.8.9 Car Ownership

Economic growth raises households' income to make cars affordable and to promote car ownership. At the same time, car ownership attracts people to live in a suburban sprawl, away from the city centre (Hayashi, 2010). This makes public transit systems, such as rail and bus transit systems, suffer from low patronage and also incur higher cost of construction for infrastructure due to increasing land values (Hayashi, 2010).

Public transport is, potentially, an important substitute for the car and recent research suggests that its presence may have an important impact on urban congestion (Anderson, 2014). Governments are trying to tackle this problem in different ways, ranging from road taxes levied on car usage, toll charges for cars entering city business districts (e.g., most recently in London) and other high traffic areas during the day, as well as controlling the growth of the vehicle population through ownership taxes. Singapore has implemented the Area Licensing Scheme (ALS), the Vehicle Quota System (VQS) and the Electronic Road Pricing Scheme (ERP) to control urban congestion.

Increasing car ownership needs to provide more parking spaces as well. For an analysis of the impact of car ownership on on-street parking, four specific challenges arise: 1) the endogeneity between residential parking and car ownership, 2) the high correlation between on-street and off-street parking, 3) the lack of off-street parking data, and 4) the measurement of the availability of on-street parking (Guo, 2013). By all these, it can be concluded the car ownership matters in a range of transport and land use decisions, thus predicting the car ownership data would give much help for decision makers to lay the proper policies to reduce the congestion, improve the public transportation, allocate spaces for car parking, etc.

3.9 Social and Environmental Impacts with Travel Changes

Today, there is a higher concern throughout over the environmental aspect. In order to mitigate the bad occurrence to the environment, different types of legal provisions have also been given. Although legal provisions are exist, due to lack of proper mechanism to correctly measure the impacts still so many problems are occurred with transport and other projects. It has been argued widely that existing transportation systems are not sustainable due to many reasons: 1) it uses a finite fossil fuel, 2) this fuel creates local air-quality problems, 3) this fuel contributes to global warming, 4) the system produces an excessive number of fatalities and injuries, and 5) the system suffers from the congestion in major urban area (Black).

There has been a significant effort lately to identify the major externalities associated with the dominant highway-motor vehicle transportation system. Although no one questions internalized costs such as fuel, insurance, registration, and the like same cannot be said for the external costs (Black). These include accident costs not covered by insurance, the medical costs of local air pollution, the cost of policing the highway system, the loss of productivity caused by motor vehicle accident injuries or fatalities, time loss by personal and commercial vehicles users due to congestion, and the like (Black). The single biggest challenge to conducting effective and efficient environmental analysis during the transportation development process is related to the amount of time it takes to advance a project from the planning phase, through final design, to construction (Willis). Due to the inability of quantifying these figures correctly in less time, these costs usually are borne by individuals or society, not by the transportation sector.

Further, IOCGP (2003) defines social impacts on transportation and land use changes as "the consequences to human populations of any public or private actions that alter the ways in which people live, work, play, relate to one another, organize to meet their needs and generally cope as members of society". The social impacts of transport and their distributional effects across various segment of society have traditionally been viewed as second or even tertiary concerns relative to economic and environmental impacts (Markovich and Lucas, 2000). According to Sinha and Labi, quantification of destruction of human-made resources, social values, community cohesion, availability of public facilities and services, displacement of people, business and farms, and disruption of desirable community and regional growth is essential for the social justification of people especially in transport projects. Lack of present and predicted quantified values of theses impacts have kept the decision makers away from getting right decisions and right times. These quantified values have been essential for decision making today.

3.9.1 Preparation and Evaluation of Policies and Projects

Policies are strategic movements of different sectors, thus, all are working towards them. If policies are not accurate, it tends make errors everywhere. Therefore, policies should be prepared more carefully. If it is able to know the future scenarios and impacts of implementing policies in advance, it is very important to prepare policies correctly.

Same as that, coming to know the future situations, authorities can identify most important projects to be identified. By looking at the future, authorities propose projects such as highways, bypass roads, road widening projects, airports, etc. They highly need to analyze whether these projects would achieve the pre-defined objectives and, positive and negative impacts of them. These will helpful for them to take correct decisions always.

Table 3.8: Analysis of Output Parameters

Output Parameter	**Importance of the present decision making process**	**Comments**
Origin-Destination Matrix	Most important	
Traffic volumes	Most important	Can generate from the O-D matrix.
Land values and rents	Less important	Can generate from socio-economic relations.
Changes of retail floor spaces	Less important	Not taken into the analysis.
Changes of locations of jobs and houses	Less important	Can generate from socio-economic relations.
Changes of locations of industries	Less important	Can generate from socio-economic relations.
Population distribution	Important	Can generate from socio-economic relations.
Car ownership	Important	Can generate from socio-economic relations.
Social impacts	Important	Not taken into the analysis.
Environmental impacts	Important	Not taken into the analysis.

All these output parameters are important for decision making. Here, it can be observed that the generation of an accurate O-D matrix can further produce many important outputs here. By analyzing all these, the modeling techniques, input parameters and output parameters for the macro model and micro model were decided as follows.

Table 3.9: Selected Modeling Techniques, Input Parameters and Output Parameters for Macro Model and Micro Model

Model Type	Modeling Technique	Input Parameters	Selected Output Parameters	Data used to Model Validation
Macro Model	Mathematical models developed by the regression analysis using O-D matrix data and socio-economic data.	▪ Birth and death rates ▪ Population data ▪ Immigration and emigration data ▪ No of households ▪ Household income and size ▪ Number of children ▪ Number of workers ▪ Schools and universities data ▪ Job sectors ▪ Labor details ▪ Inflation data ▪ Import and export details ▪ Environmental data ▪ Number of trips ▪ Road network database ▪ Car ownership data ▪ Job salaries ▪ Land use data ▪ Land rents ▪ Land values	▪ Origin-Destination matrix ▪ Link volumes ▪ Node volumes ▪ Travel speed ▪ Travel time ▪ Congestion level Land values and rents ▪ Changes of locations of jobs and houses ▪ Population distribution ▪ Car-ownership	Number of trips
Micro model	Micro-simulation	▪ Household o-d survey data	▪ Origin-destination matrix	Number of trips

		▪ Railway passengers o-d surveys ▪ No of households ▪ Road network database ▪ Land use data	▪ Link volumes ▪ Node volumes ▪ Travel speed ▪ Travel time ▪ Congestion level	

3.10 Geographical Information System (GIS) and User Interfaces

A geographic information system or Geographical Information System (GIS), which comes in the means of software programs, is a system designed to capture, store, manipulate, analyze, manage, and present all types of spatial or geographical data (Wikipedia). Today, the spatial information is at a great necessity for the right decision making. Today, 70-80% of the tasks solved by planning related authorities are geographically related. In many situations, the knowledge of the place where something happens can be critically important (Kopackova, Komarkova and Sedlak, 2014). Data which contains spatial information are special as they allow to link place, time and attributes. Specially transport and land use aspects need the spatial information as all decisions are implemented on the land. Therefore, GIS provides a framework to inform models, such as those used to forecast travel demand and plan capital improvements and to support strategic decision-making (Motamed). In addition, GIS applications for making environment evaluations can shed light on the consequences for various transportation alternatives.

Further, a user interface is that portion of an interactive computer system that communicates with the user. The user interfaces are becoming a larger and larger portion of the software in a computer system and a more important portion, as broader groups of people use computers (Jacob, 2000). As computers become more powerful, the critical bottleneck in applying computer-based systems to solve problems is now more often in user interfaces, rather than the computer hardware or software. Therefore, proper design of user interfaces can make a substantial difference in training time, performance speed, error rates, user satisfaction, and the user's retention of knowledge of operations over time. Thus, proposed transport and land use model can do a great job here with the carefully designed more sophisticated user interfaces.

3.11 Conclusion

Variety of models are in operation today and these models have been developed using different modeling techniques, input parameters and output parameters. GIS concept, which comes out by different means of software programs, has been incorporated in most of models. Although, the modeling techniques are the first to be selected, it seems, modeling techniques highly depend on the input and output parameters. Therefore, a comparative analysis of modeling techniques, available input parameters and desired output parameters should be done simultaneously to find appropriate model parameters. Most models are from developed countries, where the high accuracy different data sets are available. Therefore, different types of models are available. But, in Sri Lankan situation, where the accurate data are extremely limited, selecting a modeling techniques should be carefully analyzed as little money is available for data collection. Due to the lack of data, regular validations cannot be done. This is another factor that needs to be considered before selecting modeling techniques. Therefore, mathematical modeling framework is the most appropriate modeling technique for a country like Sri Lanka. Although, the preparation of O-D matrix is costly in the beginning, lack of data required time to time for predicting purposes would release the pressure for prospective users. Still, most decision bodies have the faith on survey data, as those are closer to reality. As census data are readily available, mathematical equations built from regression analysis using OD data and socio-economic data is the most practical attempt here. Errors occurred in these equations can be further reduced by the proper validation. Here validation would not account much cost.

But, when comes to the micro level, as explained earlier, the activity based approach is the most appropriate and it is one of techniques used in the most accepted microsimulation modeling. Here, data needs to be collected at household level and as the area is small, it would be more practical.

CHAPTER 04: MACRO MODEL

4.1 Introduction

Macro model, which is helpful for the national and regional level transport and land use planning, focuses on whole Sri Lanka. Here Divisional Secretariat Divisions (DSDs) were taken as the Transport Analyzing Zones (TAZs). Therefore, in the macro model, data aggregation was done to DSD level. There are 331 DSDs in Sri Lanka making 109,561 O-D pairs. As mentioned in the previous chapter, only A and B class roads were used but C class roads were used in few occasions where A and B class roads could not be found to complete the O-D pair. Road transportation is only considered here in order to reduce the complexity as well as assuming road transportation needs more solutions. Macro modeling technique was built upon the O-D matrix. After deciding to use the O-D matrix based regression analysis algorithms in the macro model, the first task was to produce an accurate O-D matrix.

4.2 Origin-Destination Matrix

An Origin-Destination matrix (O/D) is a spatially disaggregated measure of the traffic demand within a defined study area. The origin-destination trip table depicts the spatial distribution of trips among Traffic Analysis Zones (TAZs) in a transportation network (Yang, 2004). Moreover, Origin-Destination surveys comprise information about the spatial and temporal distribution of activities between different traffic zones in a study area. These surveys are primarily used to estimate the present demand for transport systems, then by, integrating projections of economic and population growths, predicted land use changes, planning policies, etc., secondarily used to estimate the future demand as well. Origin-destination trips are assigned to a transportation network that is spatially defined to represent the actual transportation system (Meyer and Miller, 2001). Therefore, Origin-Destination (O/D) matrices are of vital importance for transportation systems operation, design, analysis, and planning.

O-D surveys, which have great importance of transport planning process, are conducted by different methods by different studies. Some of methods frequently observed are road-side interviews, house-hold interviews, telephone interviews, on-board transit surveys, mailed questionnaires and pick-up postal cards. Each of these methods has its own advantages and disadvantages. Selecting a proper method for O-D surveys should be done carefully with the objectives, cost factors and time frames of the study. Moreover, in the O/D estimation process, the quality of the estimated O/D data is highly depended on accuracy of the input data, which is a subsequent factor of the selection of perfect number and locations of observation (Kattan and Abdulhai). Further, it is well noted that the quality of the estimated O-D trip table depends on the estimated methods, an appropriate set of links with traffic counts, and the quality of the traffic counts (Chen et al, 2007).

4.2.1 Optimum Counting Locations for O-D Surveys

Here, the discussion is held generally relevant to the road-side interview O-D surveys. In most occasions, the practice is that survey stations are generally located where roads cross “screen-lines”, which are imaginary barriers drawn to intercept the trip types of interest. Intuitively, the traffic counting stations are located at critical points on the network such as congested intersections and freeway entrances. Clearly, this subjective selection cannot guarantee the quality of information obtained.

Although, O-D surveys consist with many uses, several requirements are to be fulfilled in order to make it useful. It is not cost effective and practical to do O-D surveys on all the desired locations. Although it is affordable, several problems may be encountered. If counting locations are not carefully selected two major problems can be faced. Those are double counting problem and leaky screen-line problem.

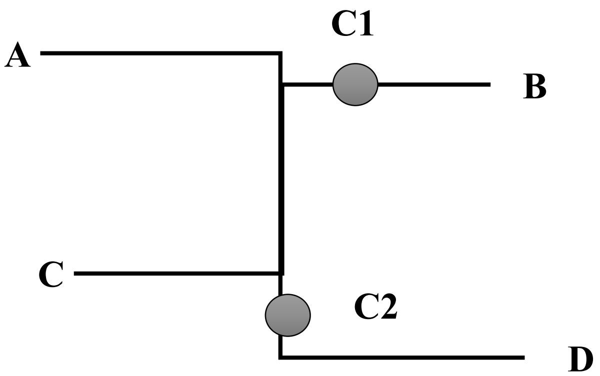


Figure 4.1: Plotting Counting Locations

Double counting problem is that some trips specially the long distance trips may pass through more than one survey station location; thus certain trips have the possibility of being sampled and expanded more than once, leading to a potentially serious overrepresentation of long distance trips in the complete expanded trip table. While, some trips may miss the survey stations entirely, leading to an underestimation of certain O-D patterns, or to distorted estimates if such sites are arbitrarily coupled with actual nearby station locations, where leaky screen-line problem is happened. According to the above figure, the BD pair is doubled counted by C1 and C2 counting locations and AC pair falls into the leaky screen-line problem as no counting location is established.

The US 81 corridor study, which was conducted at the Chickasha area, the license plate surveys were conducted to determine the amount of traffic that could potentially make use of a Chickasha bypass. Here, the combined analysis of ‘Origin’ and ‘Destination’ points to determine the number of vehicles traveling ‘from’ and ‘to’ specific locations would result in double counting of vehicles and hence was not performed. The ‘Destination’ point traffic was not included to avoid double counting of vehicles. Moreover, Government of Mozambique conducted the Maputo Bus Study Project to study the potential for the creation of co-operatives for the management and operation of mini-buses in Maputo. Origin-Destination interviews were one of the major surveys carried out here for the data collection. At the analysis stage of the Origin-Destination data, study team observed some double counting of services which served more than one of the terminals and in addition, the frequencies of some of the routes were underestimated and other services, particularly those from the outside Maputo, would probably not have been observed at the terminals. But study team had no solution to overcome these situations and did some manual adjustments only.

El-Geneidy et al (2010) in their research paper, “Pedestrian access to transit: Identifying redundancies and gaps using a variable service area analysis”, uses detailed Origin-Destination survey information to generate variable service areas that defines walking catchment areas around transit services in the Montreal region. A total of 16,113 transit stops were used here. The number of stops excludes the directional effect of the service to avoid double counting. Double counting occurs when two transit stations serving the same route are present across the street from each other, yet each one of them is serving different direction.

It can be seen last from all these examples that analysis of double counting and leaky screen-line errors has been carried out once the data collection has been completed.

4.2.1.1 Previous Studies

Yang (1991-2004) has put great concentration on this concept and come up with numerous solutions involving different techniques in collaboration with other scholars. Many scholars see that central problem at the preparation of O-D table is the traffic counting problem where it thoroughly needed the determination of number and locations of traffic counting stations that would best cover the network. Initially Yang et al (1991) proposed the O-D covering rule in which traffic counting stations are located in such way that total trips between each O-D pair are at least partially covered. Later, Yang and Zhou (1998) further derived four location rules and formulated various integer programs to select the traffic counting stations. These solutions were backed by the concept of Maximal Possible Relative Error (MPRE) proposed by Yang et al (1991). But these solutions were not compatible with general road networks as the data related to the path enumeration is mostly required. Yang et al. (2001) recently relaxed these assumptions and formulated the traffic counting location problem using the O-D separation rule in which path enumeration is not required and where only network topology is considered. Here genetic algorithm (GA), which is considered as one of the most practical techniques due to its simplicity and flexibility, was used to solve two traffic counting location problems: one is to locate a given number of traffic counting stations to separate as many O-D pairs as possible and the other is to determine the minimal number and locations of traffic counting stations required to separate all O-D pairs. Under this circumstance, it is important to understand the tradeoff between these two objectives in order to make a proper decision. Multi-objective optimization techniques have been considered to fulfill this requirement.

Further, Ehlert et al (2006) adopted “O-D covering rule” to develop “second best” solution to locate additional counting stations with budget consideration. Tomas presented an application of Constraint Logic Programming (CLP) for finding the minimum number and location of count-posts at urban roundabouts so as to obtain origin-destination data at a minimum cost. Lam and Lo (1990) and Yim and Lam (1998) proposed some heuristic procedures for identifying the order which the link should be selected.

Bianco et al (2001) developed an iterative two-stage procedure that first derives the complete traffic flow vector in a network and then produces a reliable O-D trip table estimate. The procedure is based on the flow measurements provided by a minimal cost set of traffic sensors that are replaced on the network by solving the sensor location problem that requires knowledge of traffic turning coefficients at each node. Chen et al (2007) suggests that a potentially better strategy for selecting traffic counting locations for practical O-D estimation could be based on two principles: 1) make sure critical links such as major corridors and gateway links are sufficiently covered, and 2) links not covered in the major corridors should be strategically included to improve the overall reasonableness of the resultant O-D.

Finally, scholars see that both double counting and leaky screen-line are problems in O-D surveys. But greater doubt exists whether all these people look on this aspect correctly. Although different methods have been produced but still there is no concrete foundation, theory or mechanism to find optimum counting locations, which eliminate both double counting and leaky screen-line problems. Further, most of cases described above took cost factor as the major determinant for locating counting posts rather than the level of accuracy.

4.3 Proposed Method

The process proposed is very simple despite the fact that it takes little time to solve manually. This method follows the O-D covering rule proposed by Yang et al (1991). Cost factor has not been considered as the major determinant here, which is the major factor in most of the existing mechanisms, but whole concentration is given to the level of accuracy, which minimize both double counting and leaky screen-line problems to a greater extent. While creating very few double counting opportunities, this mechanism well identify where it happens and thereby it is easily to be solved.

Ultimately O-D table will not occupy both double counting and leaky screen-line problems at all.

This mechanism is named as the top-down approach as it solves the by two approaches. If the number of TAZs is less than 30, as it gives only 435 pairs, the top level approach is slightly enough and hence the down approach is not required. But in most of O-D surveys, with the required level of accuracy, the number of TAZs is more than 30. Because still the study area is small, in transportation, effects from outside also have to be examined. The problem behind the one level is that, in half way, the process has to be stopped as, if it continues further, it leaves either lots of O-D pairs are double counted or not counted at all. Therefore, top-down approach is compulsory as per this mechanism if the number of TAZs is more than 30.

4.3.1 Top-Down Approach

Here, to begin with, the size of the actual TAZ should be decided upon the level of accuracy required for the study. Afterward, the study area is divided virtually into nearly 20-30 TAZs. This can be done by adding actual TAZs systematically. Considering Sri Lankan situation, there are 331 TAZs, which cannot be solved by only one approach. Further, districts seem to be the ideal virtual TAZs as there are only 25 districts.

4.3.1.1 Top Approach

Top approach is to find the optimum counting locations that cover all the O-D pairs of virtual TAZs. This follows several steps.

1) Find the possible O-D counting locations (PCLs)

All road crossing points between initial TAZ boundaries are taken as possible counting locations.

2) Find the shortest paths for all O-D pairs in favor of distance or travel time

GIS software such as Arc Map can be a good supportive tool in this regard.

3) Find the possible counting locations for each O-D pair

Minimum path connecting a given OD pair may pass through one or more of initial counting locations. Here, each O-D pair finds one or set of counting locations most occasions. If not, some extra possible counting locations can be added. Here, extra counting locations cannot be added simply as it affects to other pairs as well. If extra pairs are added, then already solved O-D pairs should be updated with newly added possible counting locations if those are passed by.

4) Selection of optimum counting locations (OCLs)

At the outset, it should be calculated that in how many O-D pairs that each possible counting locations are visible. PCLs that do not occupy any of O-D pairs are removed at first from further inspection.

Then, the counting location, which has been repeated in the highest number of pairs, will be selected as the first of optimum counting locations. All possible counting locations exist in the O-D pairs where particular selected counting location is removed from further analysis. This is to stop double counting opportunities. The reason behind this is, if one of them is selected in later analysis, corresponding O-D pairs will be double counted. After selecting first optimum counting location and removing all associated counting locations, next highest occurring counting location will be selected as the second of optimum counting locations. Again all the associated counting locations are removed. Accordingly, same process will be continued until all PCLs are removed.

At this stage, there is a set of OCLs. This set of OCLs does not create double counting problem at all and usually there will be O-D pairs that are not counted by this set of OCLs, although it is very few. It there are O-D pairs that are not counted by selected set of OCLs; another stage needs to be processed to cover those. After this stage, all newly adding OCLs will create double counting opportunities, but main advantage is that it is correctly-known where it happens.

O-D pairs that are not counted from OCLs will be taken to the next stage analysis here with all the existing PCLs. Again same process will be adopted as above for only these O-D pairs. This step will add some locations to the set of OCLs. If still there are O-D pairs with no counting locations even with new set of OCLs, same process should be followed until the selected OCLs fulfill all O-D pairs.

With the final set of OCLs, it can be guaranteed that leaky screen-line problem is not so far visible with virtual TAZs. There will be double counting problem with the added OCLs, but this mechanism well identify where the double counting is occurred and thereby, it can be easily solved at the preparation of O-D table. Finally, all the OCLs are equipped with both counting and removing lists as required.

4.3.1.2 Down Approach

This stage finalizes the OCLs. This approach works with actual TAZs and this as well continues in several steps. First and foremost, a map needs to be prepared. As a base, all the actual TAZs are shown here. Each OCL and its respective O-D paths are shown in same color in order to identify them easily. Other than that, road layers and PCLs also are illustrated in different layers.

Down approach mainly tries to adjust the O-D paths of actual TAZs with selected OCLs from the top approach. In so doing, analysis work faces three encounters here mainly.

1) Paths going through one counting location

This is the usual encounter in the analysis part. This does not create much headache and particular path should be added to the counting location with the same color in the map. Objective behind adding to the map is to make sure, if more counting locations are added further, whether the particular path added is double counted or not. It is easy for this investigation, if this part is completed considering all O-D pairs at earliest.

2) Paths going through more than one counting location

One counting location has to be chosen first. It will make easy in the data analysis stage later to choose the counting location that does not have removing list. If there are more than one of such, counting location, which counts highest number of O-D pairs, can be selected. If all counting locations have removing list, then, counting locations with least number of removing O-D pairs can be selected. After selecting one, remove list should be updated with the particular path in rest of counting locations here. Finally, path should be added to the map in the same color as the selected counting location.

3) Paths not going through counting location

Here, one more counting location should be added to count the O-D path. Selecting the counting location should try to avoid the all the paths available in the map so far. If this can be avoided that a counting location will be added to set of OCLs and will be displayed at the map with the respective path in a different color. In a situation that new counting location has to be added on exiting path or paths. Then all the existing path or paths should be included in the removal list of newly added counting location.

This level should be carried out after completing above two levels to all O-D pairs. Analysis will be more complex if this level is continued simultaneously to other two levels as more counting locations have to be added. But in between this process, due to adding of new counting location, some new paths will come either going through one or more than one counting locations.

4.4 Case Study

Here, the O-D matrix is to be prepared covering whole Sri Lanka and taking the DS Divisions as TAZs. Entire Sri Lanka was taken as the study area for this investigation. It has a total area of 65,610 square kilometers. Administratively and many aspects of planning, basically, 9 provinces can be seen. Then, there are 25 districts lie under these 9 provinces. The districts are further subdivided into 331 divisional secretariats, and these, in turn, to 14,008 Grama Niladhari divisions. Transportation in Sri Lanka is based mainly on the road network which is centered on Sri Lanka’s capital, Colombo. Road transport accounts for about 93 percent of the land transport in Sri Lanka and there are 12,000 km of A class and B class roads and nearly 100 km of expressways. There is also a railway network, which handles a small fraction of the country’s transport needs. Although, there are some domestic airline services available in Sri Lanka, air transport is easily negligible.

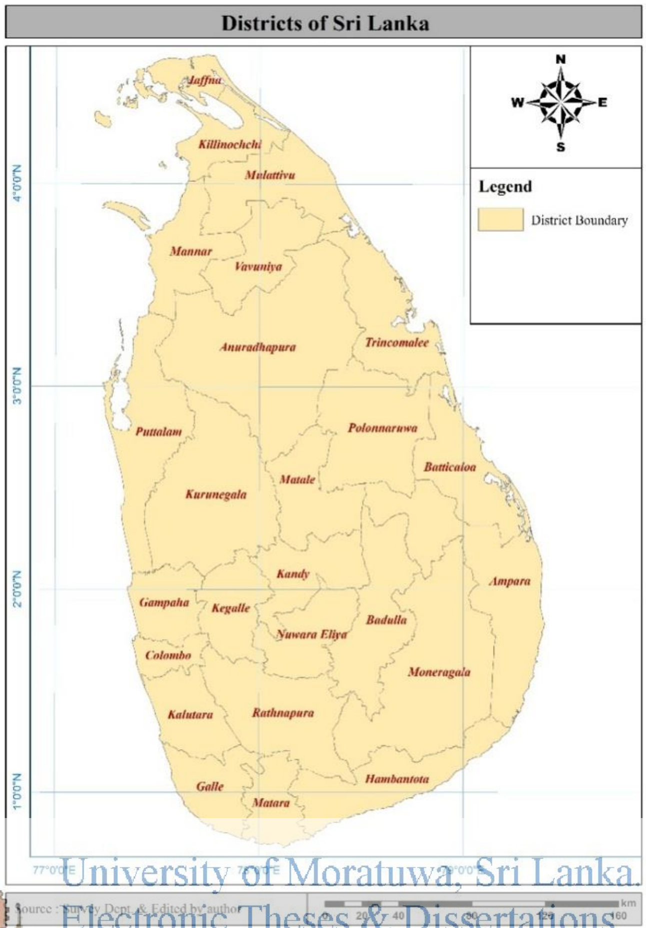


Figure 4.2: Districts of Sri Lanka

Only road transportation is considered here. The DS division level is the most appropriate Traffic Analysis Zone (TAZ) to develop an island wide O-D matrix. But, it seems impossible to find directly the optimum counting locations for DS level as nearly 50,000 O-D pairs to be evaluated. Therefore analyzes were carried out in the top-down approach. Initially district level analysis was carried out as the top approach. Then, with the results of district level, DS level results were obtained following down approach.

4.4.1 Top Approach - District Level Analysis

District level analysis can also be considered as the regional level analysis. At first, a matrix was prepared comprising all districts for both directions.

Basis to counting locations, all cutting edges between districts in the means of A and B class roads were taken as the possible locations for O-D surveys. Main argument following at this juncture is that 80% of district boundary demarcations have been done accounting water bodies, thus, bridges are seems to be the main linkage between districts. Mainly, there were 138 possible OD locations (C1-C138). Other than that all the interchanges of the southern expressway also were taken as possible OD locations (I1-I11).

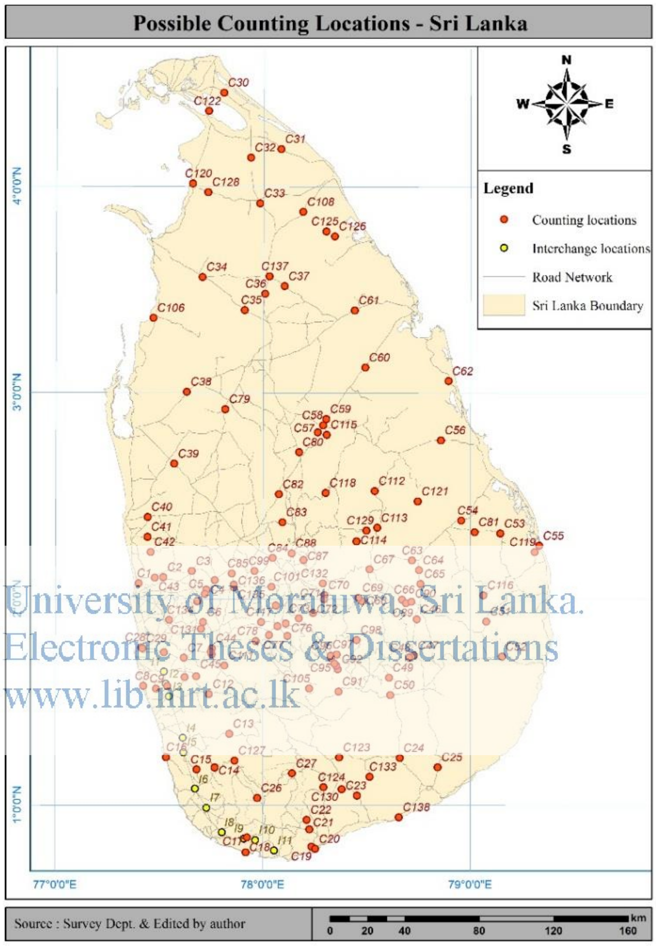
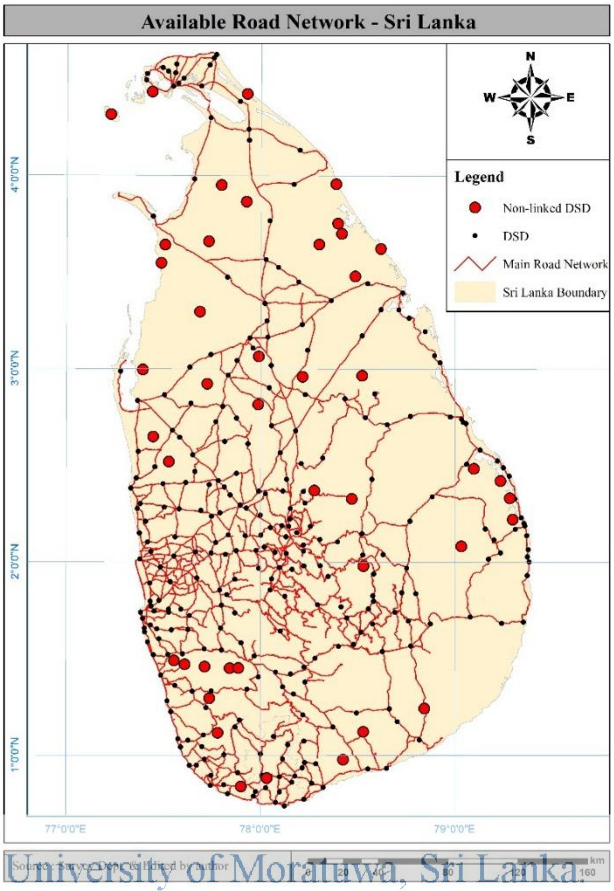


Figure 4.3: Possible Counting Locations

For this study, city with the same name, which is the district capital, was considered as the center point of the district. As an example, Anuradhapura city is the center point of the Anuradhapura District. There are many things to confirm the soundness of this argument and no slight evidences could be found in all districts, which could be used to turn aside from this. Here, it is considered that within the district, all trips are begun and ended up at the center point.



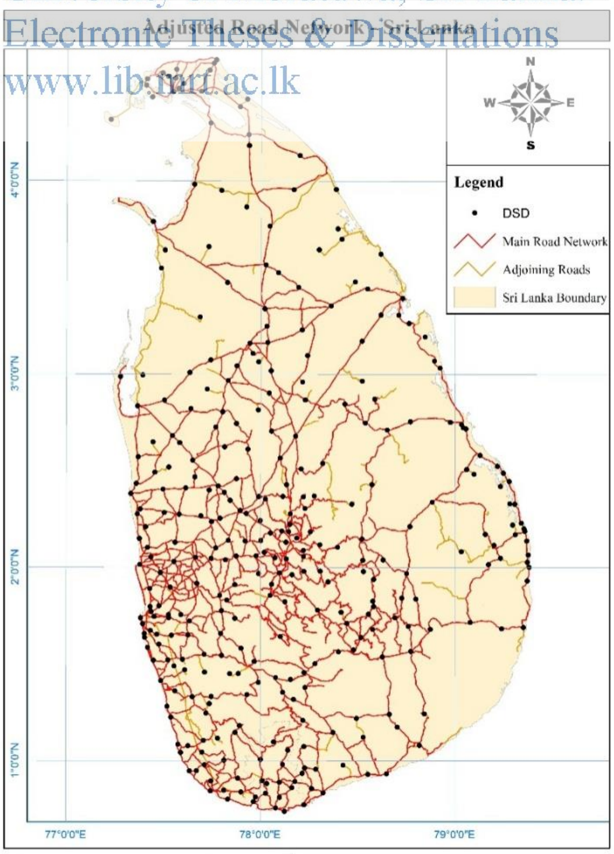
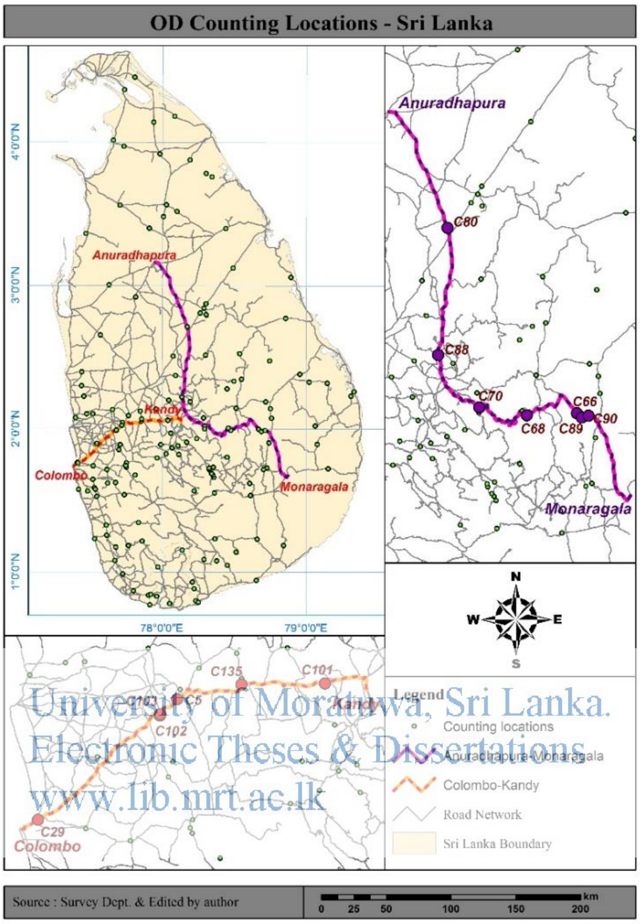


Figure 4.4: Preparation of Road Network Map

4.4.1.1 Mapping of Possible O-D Counting Locations

Then, possible counting locations were plotted to each O-D pair. It is assumed that all O-D pairs use the shortest path in favor of distance.



A	B	Colombo	Kalutara	Anuradhapura	Kegalle
1	Colombo				
2	Kalutara	C8			
3	Anuradhapura	C29, C3, C79	I3, I1, C7, C3, C79		
4	Kegalle	C29, C102, C103, C5	I3, I1, C44	C79, C85	
5	Kandy	C29, C102, C103, C5,C101,C135	I3, I1, C7, C102, C103, C5, C101	C80, C88	C101
6	Jaffna	C29, C102, C103, C5, C86, C82, C80, C36, C33, C32	C8, C28,C1,C120, C106,C107	C122, C36, C33, C32	C85, C82, C80, C36, C33, C32
7	Kilinochchi	C29, C102, C103, C5, C86, C82, C80, C36, C33, C32	I3, I1, C7, C3, C79, C36, C33, C32	C36, C33, C32	C85, C82, C80, C36, C33, C32
15	Monaragala	C7, C104, C45, C91, C50	C12, C91, C50	C80, C88, C70, C68,C66,C90, C89	C111, C91, C50
8	Puttalam	C28, C1	C8, C28, C1	C38	C85, C39
9	Polonnaruwa	C29, C102, C103, C86, C82, C57	I3, I1, C7, C102, C103, C5, C86, C82, C57, C58	C58	C85, C82, C115
10	Trincomalee	C29, C102, C103, C5, C86, C82, C57, C59, C60	I3, I1, C7, C102, C103, C5, C86, C82, C57, C59,	C61	C85, C82, C57, C59, C60

Figure 4.5: Possible Counting Locations for O-D Pairs

Network analysis tool in Arc GIS 10.0 was used to find the shortest path. As an example, possible counting locations for Colombo to Kandy are C29, C102, C103, C5, C135 and C101, and for Anuradhapura to Monaragala O-D pair are C80, C88, C70, C68, C66, C90 and C89.When plotting the counting locations for OD pairs, another 16 potential counting locations (from C123 to C138) have to be added as parts of some preferred paths were on the minor roads as well. Therefore, locations, where such minor roads (C and D class roads) cut district boundaries, were also taken into the study here.

4.4.1.2 Number of O-D Pairs at Each Counting Location

Initially, it was calculated that in how many O-D pairs each counting location was appeared. Simple tally counting system was used in this regard.

Table 4.1: No. of Pairs at Each Counting Location

C_L	N_O_O	C_L	N_O_O	C_L	N_O_O	C_L	N_O_O	C_L	N_O_O	C_L	N_O_O	C_L	N_O_O	C_L	N_O_O
C1	20	C20	5	C39	10	C58	21	C77	1	C96	0	C115	0	C134	0
C2	0	C21	0	C40	0	C59	11	C78	6	C97	14	C116	3	C135	0
C3	11	C22	10	C41	0	C60	15	C79	21	C98	1	C117	0	C136	0
C4	0	C23	10	C42	0	C61	8	C80	39	C99	0	C118	3	C137	0
C5	29	C24	10	C43	0	C62	5	C81	13	C100	0	C119	3	C138	0
C6	5	C25	1	C44	12	C63	16	C82	28	C101	18	C120	9	I1	14
C7	26	C26	2	C45	7	C64	6	C83	2	C102	32	C121	2	I3	34
C8	12	C27	1	C46	0	C65	6	C84	8	C103	32	C122	20	I4	1
C9	1	C28	13	C47	2	C66	8	C85	8	C104	9	C123	10	I5	0
C10	1	C29	13	C48	0	C67	17	C86	36	C105	1	C124	10	I6	0
C11	3	C30	0	C49	12	C68	2	C87	1	C106	18	C125	3	I7	0
C12	4	C31	2	C50	7	C69	0	C88	23	C107	4	C126	3	I8	26
C13	3	C32	31	C51	12	C70	0	C89	9	C108	19	C127	2	I9	1
C14	1	C33	32	C52	0	C71	1	C90	6	C109	1	C128	1	I10	1
C15	0	C34	11	C53	12	C72	0	C91	12	C110	13	C129	2		

C_L	N_O_O	C_L	N_O_O	C_L	N_O_O	C_L	N_O_O	C_L	N_O_O	C_L	N_O_O	C_L	N_O_O	C_L	N_O_O
C16	7	C35	10	C54	3	C73	16	C92	0	C111	18	C130	0		
C17	4	C36	63	C55	13	C74	0	C93	0	C112	12	C131	3		
C18	16	C37	5	C56	9	C75	1	C94	0	C113	13	C132	1		
C19	0	C38	7	C57	17	C76	0	C95	0	C114	5	C133	1		

C_L = Counting Location N_O_O = Number of Occurrences

C36 was the highest appearing counting location that accounts 63 O-D pairs. Second highest was the C80 reporting 39 O-D pairs. It is noteworthy that out of 148 possible counting locations, 39 locations did not exist at any of O-D pairs. At very beginning these 39 counting locations were removed from the investigation.

C36 was selected at very first as one of the optimum counting locations at the regional level. Once C36 had been selected, any of other counting locations appeared in those 63 O-D pairs was removed from further examination. Then, none of 63 O-D pairs will be double counted. Here, 43 possible counting locations were removed from further analysis after selecting the C36. Again, highest occurring counting location, after removing those 43 counting locations including C36, was selected as the second optimum counting location. At next, same process were followed and removed all associated counting locations. This mechanism was continued until all the possible counting locations were taken out from the study. Here, 23 optimum counting locations were selected keeping no counting location for 103 O-D pairs.

Then analysis should be begun for these 103 O-D pairs. It is important to mention that all newly adding counting locations would create double counting problems, which should be well recorded to be solved at the final stage of the preparation of O-D matrix. Same process was followed as above for these 103 O-D pairs.

Here, 20 OCLs were selected additionally and but still keeping no counting location for 31 O-D pairs. Therefore, two more steps were followed to account all O-D pairs adding another 21 OCLs. Altogether there are 62 OCLs to cover the top approach.

Other approach. Other than the initial 23 OCLs, all other counting locations occupy removing list also. (See Annex 01 and Annex 02)

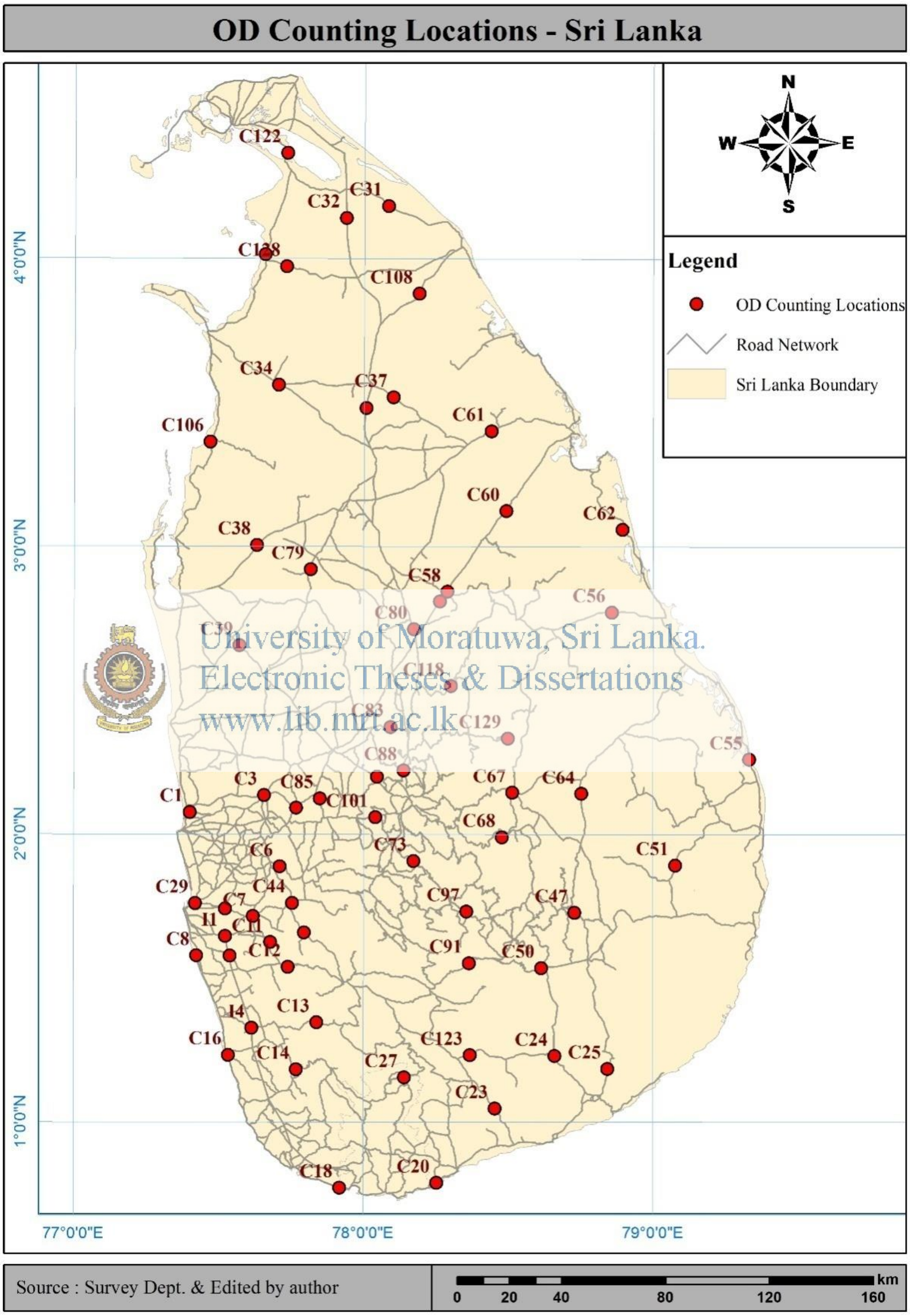


Figure 4.6: O-D Counting Locations at District Level Analysis

4.4.2 Down Approach – DS Division Level Analysis

There were 62 optimum O-D counting locations from district level analysis. It is so hard to do same level analyze to DS level directly. As same as the regional analysis part, the suburb in the name, which is same as the name of particular DS division, was considered as the center point, where it is considered all trips with the DS division are begun and ended. The same road layer used at the district level was used here.

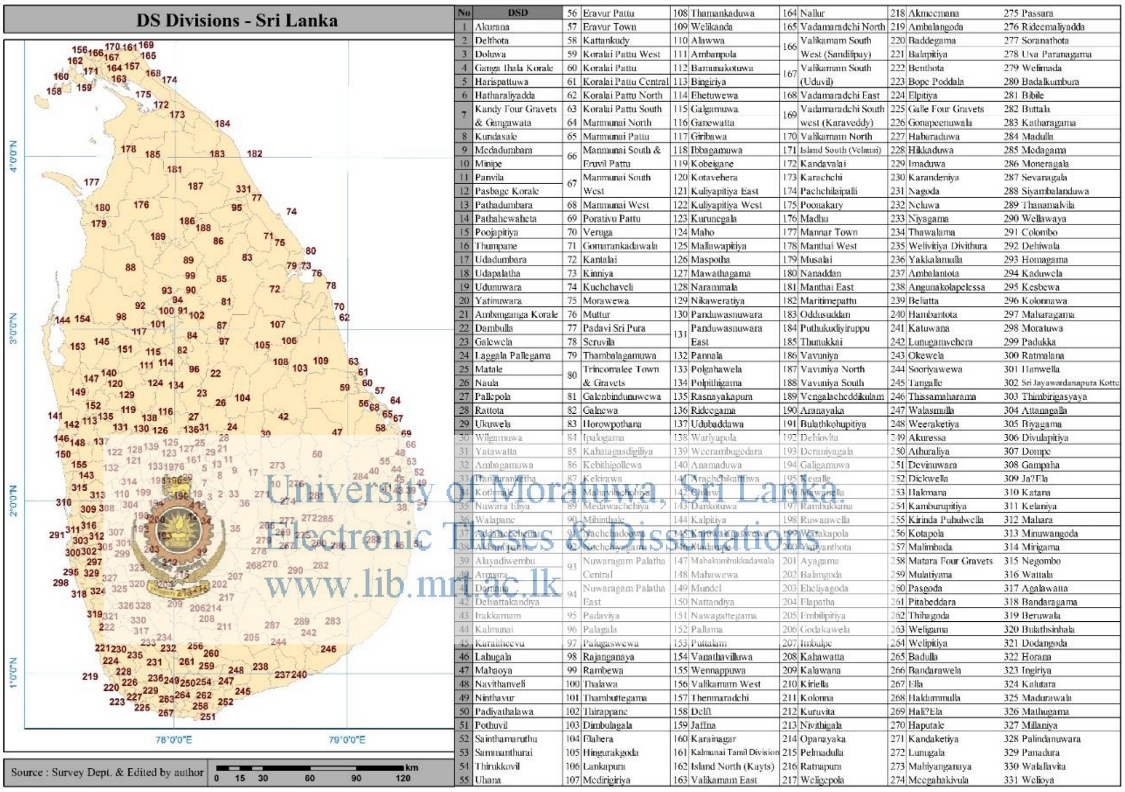


Figure 4.7: DSD Map of Sri Lanka

At the initial stage, a map was prepared using GIS software indicating 62 locations above with different colors and their respective O-D pairs in same colors. Same as the top approach, counting locations of each pair were looked on using the network analysis tool in ArcGIS software program. Not like the top approach, only 62 counting locations selected by the district level analysis used as the possible counting locations here. 4945 pairs, which are nearly only 9% from the total number of pairs, were seen without having a single counting location. In the rest of O-D pair, if there is one counting location only, counting list of the particular counting location is updated with this new O-D pair in the counting and removing list of the district level. Then in the map, particular pair is added to the respective counting location with the same color. If there is more than one counting location, the counting location, which is having the highest number of O-D pairs, was selected as the counting location for the particular O-D pair. Therefore, counting list of particular counting location is updated in the counting and removing list, and map was also updated same as above. Removing list of other counting locations was updated by the relevant O-D pair. This was carried out for all 49670 O-D pairs, which were having counting locations.

It can be observed that DS divisions those are closer to each other have not got the counting locations mostly. Further, it could be observed that many counting locations need to be added to tackle those O-D pairs. If all these counting locations were added to overall analysis, a huge mess-up could have been emerged as counting and removing lists of most of these counting locations create a complex situation making the analysis so difficult. Therefore, it was decided to take only the counting list. There are such 397 counting locations. Further, it is not practical to carry out roadside interview O-D surveys in all these counting locations. Further analysis showed that those gaps can be easily filled with the algorithms which are to be prepared at the next stage. It can be concluded that nearly 62 counting locations need much attention as each counting location accounts for a high number of O-D pairs. (See Annex 03) O-D counting pairs of each counting locations are shown in Annex 04.

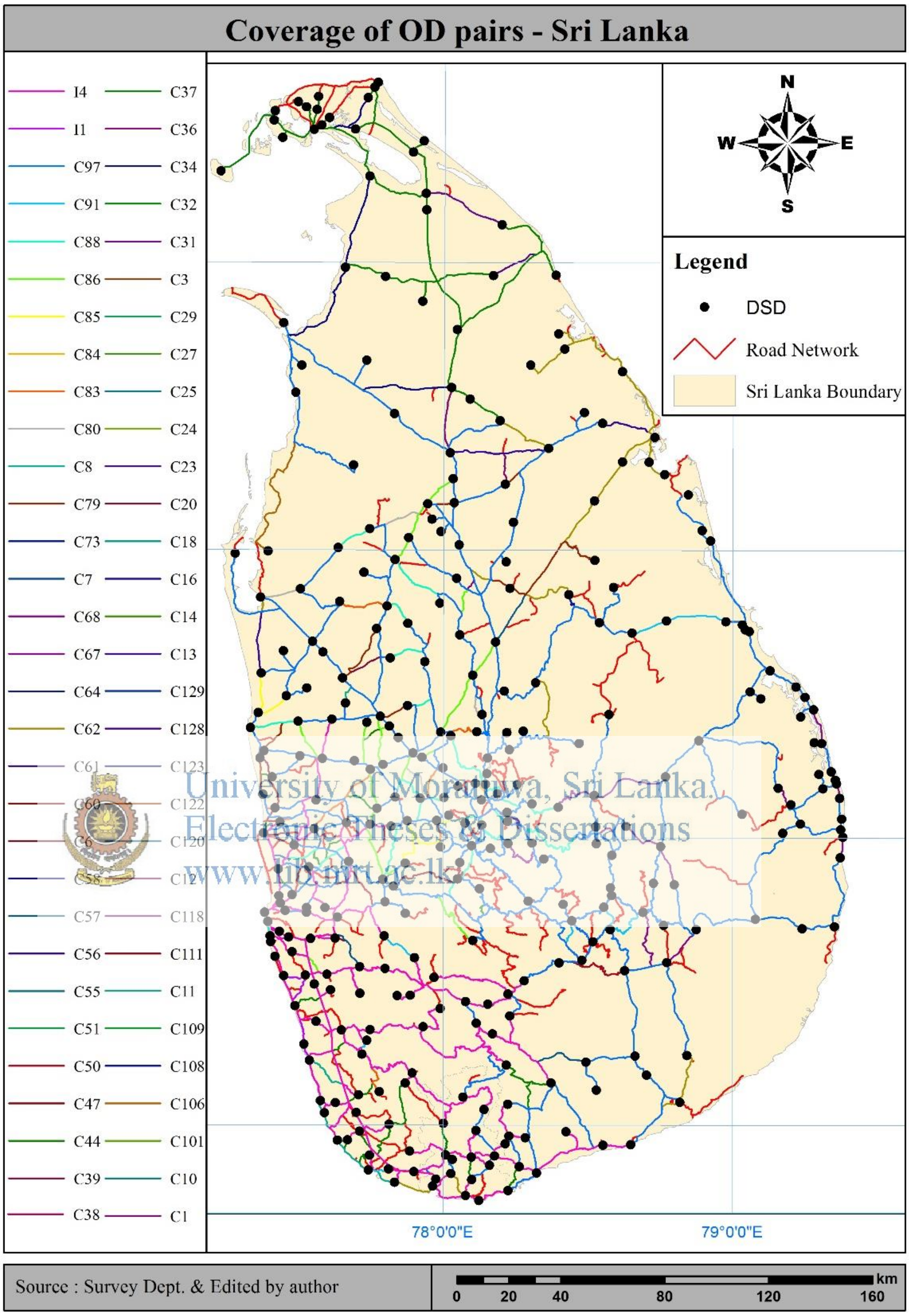


Figure 4.8: O-D pairs at DS Division Level (Combined with District Level Analysis)

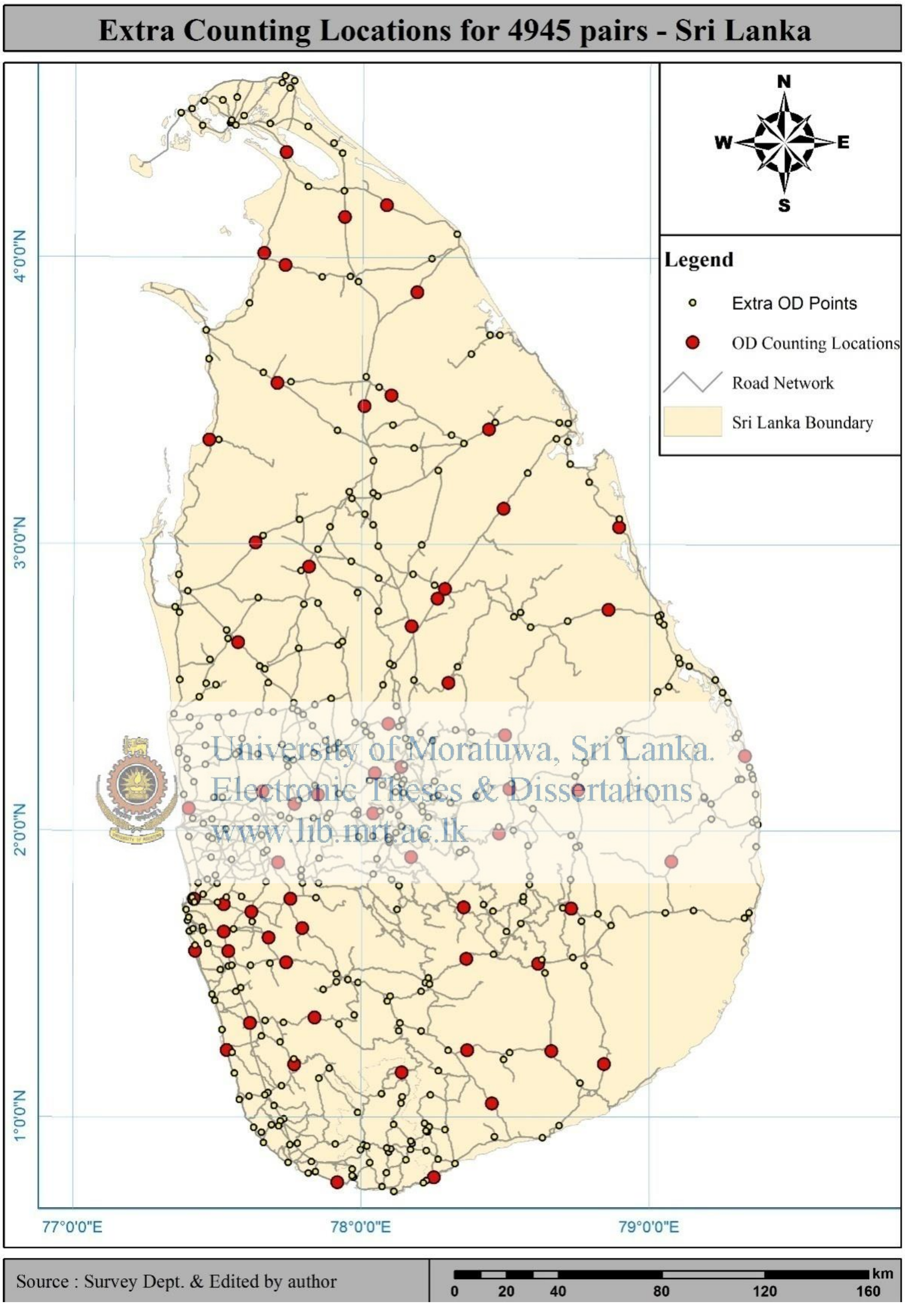


Figure 4.9: Extra Counting Location for 4945 OD Pairs

4.4.3 Sample Size Requirement

Estimation of required sample sizes rapidly becomes more complex in transport surveys. Most of times, transport surveys are answerable for larger population sizes. Also cost of doing them is very high and ever increasing. Much to the chagrin of many investigators, no firm rules can be given for sample size calculations for use in all circumstances and but guidance is exist (Richardson et al). Most scholars say that higher sample size is required for large population size, and vice-versa. Normally minimum ten percent samples are required for population less than 50,000 while population more than one million require only one percent for the same accuracy (Mathew and Rao, 2006). By convention, 95% levels of confidence are often assumed for sample surveys in transport. Moreover, the variability, over the population is one of the major factors that are considered in the sample size calculation.

In most O-D surveys, it seems that a selection criterion of sample size is deeply undervalued where it should not be. Because, invalid sample sizes of counting locations lead to wrong data in the O-D matrix and thereby it misrepresents the actual travel pattern in both present and future. Ultimately this will force authorities to take wrong decisions creating unpleasant situation in transport sector and thereby it affects to the well-being of most of sectors. Bradshaw says at one of reports to the Washington State Transport Center related the O-D surveys that it is required ten percent proportion of all traffic having a particular origin and destination on the surveyed roadway. This has been based on existing information about the survey population, traffic volumes and previous studies while achieving an accuracy of 15 percent (error) at a confidence of 95 percent. Valley Metro Regional Public Transportation Authority (RPTA) in 2007 conducted an O-D survey of the Valley Metro riders and there, the proposed plan based on three main factors: 1) the plan ensured that the sample adequately met data needs at each route level, 2) the plan ensured the collection of adequate samples at the various times of day, 3) the plan ensured that the sample was segmented by direction. Return rates as low as 10% are often expected and accepted for roadside surveys (Sussex County Ten-Year Mobility Study). Each counting location handles different number of O-D pairs. If there are sub samples, the overall sample size must be large enough that these sub samples are also enough to analyze (Ron Sellers). If the study for quick, high-level look at a particular issue, 200 or 300 may be plenty, but in order to use the data to help build a sophisticated model, probably a greater level of accuracy is required (Ron Sellers).Transportation Engineering Division of Department of Civil Engineering at the University of Moratuwa, Sri Lanka recently (2011) did some O-D surveys on behalf of Ministry of Defense closer to the Central Business District, around the city of Colombo. These O-D surveys had following sampling rates.

Table 4.2: Sampling Rates of Previous O-D Surveys

Place	No. of Passenger Vehicles ODs	No. of Freight Vehicles OD	Total No. of ODs	Total Count (Towards Colombo) (6am -7pm)	(Total No. ODs/Total Count) * 100
Piliyandala	333	77	410	6849	5.99%
Gamshaba Junction	342	105	447	6686	6.69%
Dehiwala	281	32	313	27899	1.12%
Kirulapone	851	191	1042	17488	5.96%
Kohuwala	762	151	913	16727	5.46%
Rajagiriya	579	157	736	34570	2.13%
Mattakkuliya	826	189	1015	9,697	10.47%
JF Bridge	817	395	1212	22449	5.4%
Kelani Bridge	376	430	806	36494	2.21%
Orugodawatta	368	220	588	11479	5.12%

Here, no previous surveys could be found from reliable sources on above selected optimum counting locations. Moreover, doing pilot surveys of these locations is not practical. Therefore, it was decided finally to maintain 10% sample rate at each hour with the analysis of Manual Classified Counts (MCCs).

Table 4.3: Sample Sizes at Counting Locations

No	Counting Point	Place	Towards Colombo			Other Direction		
			No of Vehicles (Surveyed)	Total No of Vehicles	Sample (%)	No of Vehicles (Surveyed)	Total No of Vehicles	Sample (%)
1	C1	Puttalam- Colombo Road	1,681	21,018	8	1,800	22,504	8
2	C3	Negambo- Giriulla Road	919	8,354	11	875	7,954	11
3	C6	Veyangoda- Ruwanwella Road	1,146	9,547	12	1,267	10,562	12
4	C7	Colombo- Hanwella Low Level Road	1,429	17,864	8	1,492	18,645	8
5	C8	Old Galle Road	1,588	19,854	8	1,648	20,598	8
6	C10	Colombo-Horana Road	821	5,864	14	850	6,542	13
7	C11	Meepe-Ingiriya Road	903	6,452	14	870	6,214	14
8	C12	PNR Highway	791	5,648	14	788	5,627	14
9	C13	Thiruwanaketiya-Agalawatta Road	835	6,421	13	797	6,133	13
10	C14	Horawela-Pelawatta Road	842	6,478	13	787	6,057	13
11	C18	Matara Road	1,194	9,946	12	1,099	8,456	13
12	C20	Tangalle Road	1,178	8,412	14	1,113	7,952	14
13	C23	Ambilipitiya-Nonagama Highway	782	6,015	13	820	6,310	13
14	C24	CGHW Highway	752	5,014	15	688	4,589	15
15	C25	Tissamaharama-Kataragama Road	900	6,428	14	958	6,842	14
16	C27	Galle-Madampe Highway	894	7,452	12	859	7,158	12
17	C29	Colombo-Kandy Highway (New Kelani Bridge)	1,175	13,055	9	1,341	16,757	8
18	C31	Parantan-Mullaitivu Highway	729	4,863	15	641	4,578	14
19	C32	Kandy-Jaffna Highway	838	5,987	14	768	5,486	14
20	C34	Medawachchiya-Talaimannar Highway	1,279	9,842	13	1,167	8,974	13

No	Counting Point	Place	Towards Colombo			Other Direction		
			No of Vehicles (Surveyed)	Total No of Vehicles	Sample (%)	No of Vehicles (Surveyed)	Total No of Vehicles	Sample (%)
21	C36	Kandy-Jaffna Highway (Iratperiyakulam)	833	5,948	14	777	5,547	14
22	C37	Vavuniya-Horowpotana Highway	688	4,587	15	628	4,189	15
23	C38	Trincomalee Road	1,046	10,456	10	946	9,456	10
24	C39	Katugastota-Puttalam Highway	930	8,456	11	874	7,945	11
25	C44	Yatiyantota Road	974	8,856	11	965	8,775	11
26	C47	Passara-Monaragala Highway	730	4,865	15	718	4,786	15
27	C50	Colombo-Batticaloa Highway	666	4,756	14	718	4,789	15
28	C51	Siyambalanduwa-Ampara Highway	584	3,894	15	728	4,856	15
29	C55	Colombo-Batticaloa Highway (Pandiruppu)	839	6,452	13	910	7,582	12
30	C56	Polonnaruwa-Welikanda Road	843	6,486	13	767	5,477	14
31	C57	Ambepussa-Trincomalee Highway	1,085	10,854	10	861	9,564	9
32	C58	Habarana- Polonnaruwa Road	868	7,895	11	822	7,469	11
33	C60	Kandy Road	818	5,842	14	777	5,547	14
34	C61	Puttalam-Trincomalee Highway	835	6,421	13	794	6,108	13
35	C62	Trincomalee Highway (Verugal)	929	7,145	13	948	7,294	13
36	C64	Peradeniya-Chenkaladi Highway	821	5,476	15	750	5,359	14
37	C67	Kandy-Padiyatalawa Highway	822	5,874	14	798	5,697	14
38	C68	Mahaweli Raja Mawatha	838	5,984	14	776	5,542	14
39	C73	PBC Highway	848	6,524	13	846	6,511	13
40	C79	Anuradhapura-Padeniya Highway	1,157	9,642	12	1,113	8,564	13
41	C80	Kandy-Jaffna Highway (Dambulla)	1,156	11,564	10	978	10,865	9
42	C83	Matale Road	927	8,425	11	875	7,954	11

No	Counting Point	Place	Towards Colombo			Other Direction		
			No of Vehicles (Surveyed)	Total No of Vehicles	Sample (%)	No of Vehicles (Surveyed)	Total No of Vehicles	Sample (%)
43	C84	Katugastota-Puttalam Highway (Paragahadeniya)	825	5,894	14	797	6,134	13
44	C85	Polgahawela-Kegalle Highway	1,136	9,466	12	984	8,946	11
45	C86	Kurunegala Road	1,163	9,689	12	1,001	9,104	11
46	C88	Matale Road (Alawatugoda)	746	4,975	15	769	5,129	15
47	C91	Colombo-Batticaloa Highway (Walhaputenna)	694	4,957	14	701	5,006	14
48	C97	Nuwara Eliya-Seetha Eliya Road	826	5,897	14	850	6,541	13
49	C101	Colombo-Kandy Highway (Kadugannawa)	956	9,563	10	962	10,684	9
50	C106	Puttalam-Mannar Road	1,124	11,236	10	1,113	12,368	9
51	C108	Puliyankulam Road	825	5,498	15	806	5,371	15
52	C109	Avissawella Road	1,259	13,994	9	1,190	14,875	8
53	C111	Colombo-Batticaloa Highway (Eheliyagoda)	1,023	11,364	9	1,122	12,468	9
54	C118	Elahera Road	845	7,045	12	792	6,598	12
55	C120	Navathkuli-Mannar Highway	1,011	8,423	12	1,027	8,561	12
56	C122	Navathkuli-Mannar Highway (Sankupitti Bridge)	918	7,654	12	932	7,763	12
57	C123	Thanamalvila Road	839	6,453	13	795	6,112	13
58	C128	Mankulam-Vellankulam Road	940	8,541	11	973	8,845	11
59	C129	Hettipola-Diyawiddagama Road (Nippon Bridge)	839	6,454	13	778	5,987	13
60	I1	Southern Expressway (Kottawa Interchange)	877	6,748	13	864	6,648	13
61	I4	Southern Expressway (Dodangoda Interchange)	839	6,451	13	821	6,315	13
62	C16	Galle Main Road (Bentota)	1,429	17,864	8	1,281	16,008	8

No	Counting Point	Place	Towards Colombo			Other Direction		
			No of Vehicles (Surveyed)	Total No of Vehicles	Sample (%)	No of Vehicles (Surveyed)	Total No of Vehicles	Sample (%)
63	C139	Sir James Peiris Mawatha	1,915	23,941	8	1,702	21,279	8
64	C140	Galle Road (Wellawatta)	2,556	31,944	8	2,695	33,685	8
65	C141	Colombo - Batticaloa Hwy (Nugegoda)	1,557	19,458	8	1,672	20,900	8
66	C142	Havelock Road (Narahenpita)	1,717	21,467	8	1,639	20,486	8
67	C143	Negombo Road (Wattala)	3,245	40,562	8	4,608	57,596	8
68	C144	Ragama Road (Neligama)	1,485	18,564	8	1,428	17,854	8
69	C145	Kadawatha - Ganemulla Road (Ganemulla)	1,317	16,457	8	1,238	15,479	8
70	C146	Ja-Ela, Ekala, Gampaha, Yakkala Hwy	1,485	18,566	8	1,508	18,849	8
71	C147	Negombo -Giriulla Road (Kandhawala)	1,175	14,689	8	1,080	13,498	8
72	C148	Minuwangoda- Dagonna - Katana Road (Miriswatta)	1,077	13,465	8	991	12,385	8
73	C149	Negombo - Mirigama Road (Gampaha)	1,253	15,664	8	1,188	14,856	8
74	C150	Chilaw - Colombo Main Road (Colombo)	1,805	22,564	8	1,885	23,566	8
75	C151	Veyangoda - Ruwanwella Road (Veyangoda)	939	10,435	9	908	10,084	9
76	C152	Ekala - Kotadeniyawa Road (Ballapana)	846	8,464	10	852	9,465	9
77	C153	Negombo - Kurunegala Road (Sandalankawa)	900	10,005	9	863	9,584	9
78	C154	Negombo - Mirigama Road (Rendapola)	864	8,642	10	851	9,461	9
79	C155	Badalgama Road (Makandura)	863	7,846	11	817	7,425	11
80	C156	Ja-Ela, Ekala, Gampaha, Yakkala Hwy (Idigolla)	852	9,465	9	881	9,785	9

No	Counting Point	Place	Towards Colombo			Other Direction		
			No of Vehicles (Surveyed)	Total No of Vehicles	Sample (%)	No of Vehicles (Surveyed)	Total No of Vehicles	Sample (%)
81	C157	Mirigama Road (Warakapola)	778	6,486	12	738	6,147	12
82	C158	Pasyala - Giriulla Road (Pasyala)	846	8,456	10	812	8,124	10
83	C159	Kaleliya - Madagampitiya Road (Pallewela)	822	6,848	12	737	6,143	12
84	C160	Toppuwa - Nattandiya - Madampe Road (Ihala Kottaramulla)	865	8,645	10	874	7,945	11
85	C161	Chilaw - Colombo Main Road (Nainamadama)	953	10,587	9	886	9,845	9
86	C162	Toppuwa - Nattandiya - Madampe Road (Walahapitiya)	841	7,645	11	868	7,894	11
87	C163	Puttalam - Colombo Road (Madampe)	895	8,945	10	819	9,104	9
88	C164	Puttalam - Colombo Road (Chilaw)	854	8,542	10	864	8,642	10
89	C165	Wariyapola Road (Kokkavila)	740	5,694	13	705	5,426	13
90	C166	Uraliyagara - Panirendawa - Willattewa (Rathmallagara)	668	5,142	13	651	5,007	13
91	C167	Kurunegala - Narammala - Madampe Road	821	6,845	12	774	6,452	12
92	C168	Marawila - Udubaddawa Road	712	5,478	13	746	5,741	13
93	C169	Anamaduwa Road (Pallama)	834	7,586	11	852	7,748	11
94	C171	Puttalam - Colombo Road (Wilpotha)	863	7,848	11	878	7,978	11
95	C172	Kurunegala - Narammala - Madampe Road (Kuliyapitiya)	861	9,568	9	847	9,411	9
96	C173	Hettipola Road (Hidiyamulla)	747	5,745	13	712	5,475	13
97	C174	Wariyapola Road (Bowatta)	656	5,047	13	699	4,995	14

No	Counting Point	Place	Towards Colombo			Other Direction		
			No of Vehicles (Surveyed)	Total No of Vehicles	Sample (%)	No of Vehicles (Surveyed)	Total No of Vehicles	Sample (%)
98	C175	Narammala - Kuliyapiyiya Road (Kithalawa)	771	6,421	12	766	6,384	12
99	C176	Wariyapola Road (Panduwasnuwara)	698	4,987	14	680	4,856	14
100	C177	Wariyapola Road (Bandara Koswatta)	676	4,826	14	636	4,541	14
101	C178	Chilaw Road (Malwana)	670	4,789	14	642	4,589	14
102	C179	Katugastota - Kurunegala - Puttalam Hwy (Werapola)	652	5,014	13	711	5,467	13
103	C180	Katugastota - Kurunegala - Puttalam Hwy (Kelimune)	710	5,465	13	721	5,544	13
104	C181	Kurunegala - Minuwangate Road (Pellandeniya)	723	5,561	13	734	5,647	13
105	C182	Ganewatta Road (Ganewatta)	666	4,758	14	674	4,812	14
106	C183	Kurunegala - Narammala - Madampe Road (Uhumiya)	668	5,142	13	694	5,341	13
107	C184	Kurunegala - Narammala - Madampe Road (Kadahapola)	681	4,865	14	633	4,522	14
108	C185	Kadahapola - Rambawewa Road (Bogahapitiya)	632	4,512	14	624	4,456	14
109	C186	Kurunegala - Narammala - Madampe Road (Narammala)	704	5,412	13	720	5,541	13
110	C187	Ambepussa - Trincomalee Hwy (Divulkumbura)	713	5,487	13	703	5,411	13
111	C188	Colombo - Kandy Hwy (Galigamuwa)	774	6,451	12	733	6,112	12
112	C189	Jaffna - Pannai - Kayts Road (Puliyankoodal)	582	4,157	14	590	4,215	14
113	C191	Jaffna - Manipe - Karainagar Road (Karainagar)	486	3,241	15	508	3,385	15

No	Counting Point	Place	Towards Colombo			Other Direction		
			No of Vehicles (Surveyed)	Total No of Vehicles	Sample (%)	No of Vehicles (Surveyed)	Total No of Vehicles	Sample (%)
114	C192	Circular Road (Chundukuli)	717	5,514	13	728	5,597	13
115	C193	Jaffna - Kankasanthurai Road (Jaffna)	709	5,456	13	733	5,641	13
116	C194	Jaffna - Manipe - Karainagar Road (Sandilipay)	585	4,178	14	568	4,055	14
117	C195	Jaffna - Manipe - Karainagar Road (Karainagar - Moolai)	467	3,114	15	486	3,241	15
118	C196	Columbuthurai Road (Chundikuli)	725	6,041	12	773	5,947	13
119	C197	Jaffna - Kankasanthurai Road (Thellippalai)	564	4,025	14	578	3,854	15
120	C198	Jaffna - Ponnalai – Point Pedro Road (Thiccam Junction)	488	3,254	15	499	3,324	15
121	C199	Jaffna - Point Pedro Road (Nallur)	538	3,589	15	568	3,788	15
122	C200	Jaffna - Point Pedro Road (Karaveddi)	518	3,456	15	531	3,541	15
123	C201	Jaffna - Point Pedro Road (Kiramakodu)	499	3,325	15	512	3,412	15
124	C202	Jaffna - Kandy Hwy (Chawakachchery)	639	4,562	14	618	4,412	14
125	C203	Chawakachcheri - Puloli Road (Manthigai)	499	3,325	15	509	3,394	15
126	C204	Kandy - Jaffna Hwy (Mirusuvil)	518	3,451	15	482	3,214	15
127	C205	Soranpattu - Thalayadi Road (MurugantháNagar)	457	3,045	15	443	2,954	15
128	C206	Kandy - Jaffna Hwy (Iyakachchi)	532	3,546	15	518	3,451	15
129	C207	Paranthan - Pooneryn Road (Nivil)	532	3,546	15	542	3,610	15
130	C208	Mankulam - Vellankulam Road (Mankulam)	547	3,647	15	532	3,547	15

No	Counting Point	Place	Towards Colombo			Other Direction		
			No of Vehicles (Surveyed)	Total No of Vehicles	Sample (%)	No of Vehicles (Surveyed)	Total No of Vehicles	Sample (%)
131	C209	Mankulam - Vellankulam Road (Mallavi)	553	3,688	15	525	3,501	15
132	C210	Paranthan - Mullativu Hwy (Tanniyuttu)	632	4,511	14	627	4,475	14
133	C211	Mankulam - Mullativu Hwy	655	4,681	14	638	4,557	14
134	C212	Kandy - Jaffna Hwy (Mankulam)	654	4,668	14	646	4,615	14
135	C213	South - Coast Road (Vankalai)	891	9,897	9	863	9,587	9
136	C214	Medawachchiya - Thalaimannar Hwy (Thallady)	532	3,548	15	518	3,454	15
137	C215	Nawathkuli - Karathivu - Mannar Hwy (Periyavilankuli)	878	7,985	11	853	7,758	11
138	C216	Medawachchiya - Thalaimannar Hwy (Medawachchiya)	666	5,123	13	652	5,017	13
139	C217	Vavuniya - Horowpothana Hwy (Madukanda)	665	4,752	14	639	4,567	14
140	C218	Medawachchiya - Kebithigollewa road (Etawiragollewa)	618	4,415	14	605	4,324	14
141	C219	Vavuniya - Horowpothana Hwy	575	4,110	14	600	3,998	15
142	C220	Pulmuddai Road	467	3,114	15	451	3,008	15
143	C236	Ambepussa - Kurunegala - Trincomalee Hwy	460	3,068	15	480	3,198	15
144	C243	Matale - Illukkumbura - Pallegama - Giradurukotte Rd (Mathale)	549	3,657	15	584	3,894	15
145	C260	Kandy - Jaffna Hwy (Rathmalgahawewa)	778	6,485	12	762	6,348	12
146	C272	Colombo - Puttalam Road (Nagawilluwa)	785	6,541	12	735	6,124	12
147	C294	Trincomalee Hwy (Eravur Town)	771	6,422	12	809	6,745	12

No	Counting Point	Place	Towards Colombo			Other Direction		
			No of Vehicles (Surveyed)	Total No of Vehicles	Sample (%)	No of Vehicles (Surveyed)	Total No of Vehicles	Sample (%)
148	C295	Colombo - Batticaloa (Kallady)	749	6,245	12	733	6,112	12
149	C308	Ganewalpola-Dachchi Hammillewa Rd, Yakalla (Yakalla)	582	3,879	15	551	3,674	15
150	C320	Colombo - Batticaloa (Thambuluvil)	766	5,894	13	746	5,742	13
151	C324	Colombo - Batticaloa Hwy (Siyabalanduwa)	632	4,513	14	650	4,642	14
152	C334	Mahiyangane Road (Wewathenna)	683	4,875	14	694	4,955	14
153	C336	Bibile - Uraniya - Mahiyangana Rd (Andaulpotha)	656	4,687	14	679	4,852	14
154	C346	Thangalle Road (Kudawella)	804	8,041	10	811	8,112	10
155	C370	Pelmadulla - Embilipitiya Hwy (Pallebedda)	757	5,823	13	721	5,547	13
156	C384	Beragala - Hali Ela Hwy (Beragala)	548	3,654	15	576	3,842	15
157	C392	Yakkalamulla - Ketanwila Road (Magedara)	519	3,458	15	540	3,597	15
158	C397	Colombo - Galle Main Road (Hikkaduwa)	1,019	11,326	9	1,012	12,645	8
159	C400	Thihagoda - Kamburupitiya - Mawarala - Kotapola Rd (Pasgoda)	760	5,847	13	746	5,742	13
160	C404	Polwatta Road (Egodaduwa)	1,166	14,569	8	1,253	15,665	8
161	C466	Katugastota - Puttalam Hwy (Nugawela)	656	4,684	14	679	4,852	14
162	C510	Weligama - Kananke Rd (Kananke)	1,324	16,549	8	1,403	17,541	8

4.5 Preparation of O-D Matrix

It was not practical to carry out surveys in all the locations. Therefore, roadside interview O-D surveys were carried out in all 62 main locations and 100 other locations. By analyzing all O-D survey data, the O-D matrix was filled. As not doing the O-D surveys in all counting locations, a few number of pairs did not get values. Comparing to all O-D pairs, the number of O-D pairs that misses the values is very minor and can be easily negligible in the model calibration. Further, those pairs can later be filled by model algorithms.

4.6 Collection of Socio-Economic Data

As specified in the chapter 3, as input parameters for the macro model, following data types were collected. All data were collected on aggregation basis to DSDs. Here, all data need to be adjusted to the 2015. Most of the data were not available to 2015; therefore those data were predicted by using appropriate methods.

Table 4.4: Input Parameters

Data Type	Available Years	Prediction Method
Population	2001, 2012	Population growth rate
No. of Households	2001, 2012	Calculated growth rate
Birth rate	2001, 2012	Calculated growth rate
Death rate	2001, 2012	Calculated growth rate
Car Ownership	2015	Not applicable
Land values	2015	A survey was carried out.
Rental Values	2015	A survey was carried out.
No. of Occupants	2001, 2012	Calculated growth rate
Total Income	2001, 2012	Calculated growth rate
Built up Area	2008, 2012	Calculated growth rate
Inter Emigration	2001, 2012	Calculated growth rate
Outer Emigration	2001, 2012	Calculated growth rate
Schools	2015	Not applicable
Residential Area	2009, 2012	Calculated growth rate
Commercial Area	2009, 2012	Calculated growth rate
Industrial Area	2009, 2012	Calculated growth rate

(See Annex 05 for Socio-Economic Database for 2015)

4.7 Preparation of Model

Here, the prime objective was to carry out the macro model calibration with the regression technique and to build two regression analysis based algorithms for trip production and trip attraction with the socio-economic data.

4.7.1 Regression Technique

The field of statistics has drastically changed since the introduction of the computer. Computational statistics is nowadays a very popular field in with many new developments of statistical methods such as algorithms and many interesting applications. The regression technique is a statistical method to fit relationship between one variable and one or more other variables. One of the primary advantages of regression-based forecasting techniques is that they use research and analysis to predict what is likely to happen in the next quarter, year or even farther into the future (Studenmund). Once equation is developed using existing data, it can be used to predict the dependent variable. The salient features of this technique are:

1. It indicates the significant relationships between dependent variable and independent variables.
2. It indicates the strength of impact of multiple independent variables on dependent variable.
3. The equation is derived is purely empirical in nature.
4. The technique is based on the premise that the regression coefficients initially established will still remain unchanged in the future and can be used in the regression equation for predicting the future travel.

4.7.1.1 Linear Regression Technique

It is one of the most widely known modeling techniques. Linear regression is usually among the first few topics which people pick while learning predictive modeling. In this technique, the dependent variable is continuous, and independent variable(s) can be continuous or discrete, and nature of regression line is linear. Linear regression establishes a relationship between the dependent variable (Y) and one or more independent variables (X) using a best fit straight line (also known as the regression line). Linear regression analysis consists of 3 stages: 1) analyzing the correlation and directionality of the data, 2) eliminate the multicollinearity, 3) estimating the model and 4) evaluating the validity and usefulness of the model.

4.7.2 Trip Production Model

Initially, the correlation between trip production and each socio-economic data was examined. The correlations derived with socio-economic data are as follows.

Table 4.5: Comparison of Correlations (Trip Production)

Trip Production		X	Ln (X)	Log_{10} (X)	Sin (X)	Cos (X)	X^2	X^3	e^x
Population	Pearson Correlation	.837	.668	.668	-.030	-.043	.754	.700	.000
	Sig. (2-tailed)	.000	.000	.000	.592	.436	.000	.000	1.000
Household	Pearson Correlation	.832	.672	.672	.096	-.058	.762	.716	.000
	Sig. (2-tailed)	.000	.000	.000	.083	.293	.000	.000	1.000
Birth Rate	Pearson Correlation	.413	.362	.362	-.019	.006	.287	.209	-.006
	Sig. (2-tailed)	.000	.000	.000	.728	.911	.000	.000	.911
Death Rate	Pearson Correlation	.666	.573	.573	-.362	.014	.596	.528	.311
	Sig. (2-tailed)	.000	.000	.000	.000	.798	.000	.000	.000
Car Ownership	Pearson Correlation	.487	.232	.232	-.064	.037	.077	.384	.000
	Sig. (2-tailed)	.000	.001	.001	.246	.504	.160	.000	1.000
Land Value	Pearson Correlation	.441	.353	.353	.015	-.139	.329	.379	a
	Sig. (2-tailed)	.000	.000	.000	.779	.012	.000	.000	.
Rental Value	Pearson Correlation	.427	.447	.447	.000	-.023	.428	.496	a
	Sig. (2-tailed)	.000	.000	.000	.994	.671	.000	.000	.
No of Occupants	Pearson Correlation	.840	.635	.635	-.025	.023	.728	.690	.000
	Sig. (2-tailed)	.000	.000	.000	.648	.681	.000	.000	1.000
Total Income	Pearson Correlation	.856	.694	.694	-.001	-.071	.748	.703	a
	Sig. (2-tailed)	.000	.000	.000	.988	.204	.000	.000	.
Builtup Area	Pearson Correlation	.227	.270	.270	-.152	.048	.002	-.019	a
	Sig. (2-tailed)	.000	.000	.000	.006	.388	.975	.726	.
Inter Emigration	Pearson Correlation		.477	.477	-.024	.006	.543	.531	.000
	Sig. (2-tailed)	.000	.000	.000	.663	.913	.000	.000	1.000
Outer Emigration	Pearson Correlation	.822	.677	.677	.053	.026	.754	.696	.000
	Sig. (2-tailed)	.000	.000	.000	.340	.636	.000	.000	1.000
Schools	Pearson Correlation	.554	.457	.457	.083	.127	.451	.373	.064
	Sig. (2-tailed)	.000	.000	.000	.131	.021	.000	.000	.249
Residential Area	Pearson Correlation	.058	.080	.080	.026	.012	.047	.025	.041
	Sig. (2-tailed)	.295	.171	.171	.635	.829	.391	.654	.459
Commercial Area	Pearson Correlation	.402	.373	.373	-.092	-.364	.360	.321	.291
	Sig. (2-tailed)	.000	.000	.000	.096	.000	.000	.000	.000
Industry Area	Pearson Correlation	.314	.300	.300	.109	-.303	.268	.229	.232
	Sig. (2-tailed)	.000	.000	.000	.049	.000	.000	.000	.000
a- Cannot be computed because at least one of the variables is constant.									

By correlation analysis, parameters, which have a higher correlation with the trip production, were selected for further analysis.

Table 4.6: Highly Correlated Parameters with Trip Production

No	**Name if the Attribute**	**Correlation**
1	Total Income	0.856
2	No of Occupants	0.84
3	Population	0.837
4	Household	0.832
5	Outer Emigration	0.822
6	Inter Emigration	0.672
7	Death Rate	0.666
8	Schools	0.554
9	Rental Value	0.499
10	Car Ownership	0.487

4.7.2.1 Checking for Multicollinearity

Then, these selected parameters were again tested for the multicollinearity as follows. Then, different combinations of parameters were found for the model calibration.

Table 4.7: Correlations between Independent Parameters (Trip Production)

		Population	**Household**	**Death rate**	**Car ownership**	**No of occupants**	**Total income**	**Inter Emigratio**	**Outer Emigratio**	**Schools**	**Rental Value[3]**
Population	Pearson Correlation	1	.996	.836	.512	.913	.907	.770	.908	.528	.419
	Sig. (2-tailed)		.000	.000	.000	.000	.000	.000	.000	.000	.000
Household	Pearson Correlation		1	.832	.505	.918	.906	.766	.904	.522	.438
	Sig. (2-tailed)			.000	.000	.000	.000	.000	.000	.000	.000
Death rate	Pearson Correlation			1	.477	.781	.779	.583	.754	.548	.256
	Sig. (2-tailed)				.000	.000	.000	.000	.000	.000	.000
Car ownership	Pearson Correlation				1	.561	.559	.393	.475	.373	.306
	Sig. (2-tailed)					.000	.000	.000	.000	.000	.000
No of occupants	Pearson Correlation					1	.974	.543	.858	.572	.425
	Sig. (2-tailed)						.000	.000	.000	.000	.000

		Population	Household	Death rate	Car ownership	No of occupants	Total income	Inter Emigratio	Outer Emigratio	Schools	Rental Value^3
Total income	Pearson Correlation						1	.536	.851	.554	.449
	Sig. (2-tailed)							.000	.000	.000	.000
Inter Emigration	Pearson Correlation							1	.813	.771	.390
	Sig. (2-tailed)								.000	.000	.000
Outer Emigration	Pearson Correlation								1	.840	.416
	Sig. (2-tailed)									.000	.000
Schools	Pearson Correlation									1	.165
	Sig. (2-tailed)										.003
Rental Value^3	Pearson Correlation										1
	Sig. (2-tailed)										

4.7.2.2 Possible Equations

Table 4.8: Model Equations for Different Parameters (Trip Production)

Model No	Input Parameter	Model Equation	R	R^2
1	Population	1.499(Population) + 0.111(Car_Ownership) - 322.846(Schools) + 2.61x10^{-10}(Rental_Value)^3 - 48975.692	0.8546	0.7303
	Car Ownership			
	Schools			
	Rental Value			
2	Household	5.915(Household) + 0.120(Car_Ownership) - 229.290(Schools) + 2.85x10^{-10}(Rental_Value)^3 - 53202.379	0.8309	0.6903
	Car Ownership			
	Schools			
	Rental Value			
3	Death Rate	18862.939 (Death_Rate) + 0.213 (Car_Ownership) + 1.103 (Inter_Emigration) + 4.63x10^{-10} (Rental_Value)^3 -56739.382	0.7861	0.6180
	Car Ownership			
	Inter Emigration			
	Rental Value			
4	Death Rate	22974.697(Death_Rate)+0.226 (Car_Ownership) + 710.499 (Schools) + 5.74x10^{-10} (Rental_Value)^3 -67028.587	0.7691	0.5915
	Car Ownership			
	Schools			
	Rental Value			
5	No of Occupants	3.794(No_of_Occupants) + 0.016 (Car_Ownership) + 0.364(Inter_Emigration) + 2.76x10^{-10} (Rental_Value)^3 -46553.245	0.7544	0.5691
	Car Ownership			
	Inter Emigration			
	Rental Value			
6	No of Occupants		0.7544	0.5692
	Car Ownership			

Model No	Input Parameter	Model Equation	R	R^2
	Schools Rental Value	4.116(No_of_Occupants) + 0.013 (Car_Ownership) + 126.013 (Schools) + 2.88x10-10 (Rental_Value) 3- 47922.728		
7	Total Income Car Ownership Inter Emigration Rental Value	9.52×10^{-5}(Total_Income) + 0.004 (Car_Ownership) + 0.328 (Inter_Emigration) + 2.32×10^{-10}(Rental_Value)^3 -41342.109	0.6650	0.4482
8	Total Income Car Ownership Schools Rental Value	1.01×10^{-4} (Total_Income) + 0.003 (Car_Ownership) + 139.550(Schools) + 2.43×10^{-10} (Rental_Value)^3 -42386.913	0.7650	0.5852
9	Outer Emigration Car Ownership Schools Rental Value	71.571(Outer_Emigration) + 0.191 (Car_Ownership) - 2022.256 (Schools) + 1.18×10^{-10} (Rental_Value)^3 -31696.476	0.7664	0.5873

4.7.2.3 Selected Model (Trip Production)

Comparing the R and R square values, following model was selected for the trip production estimates.

Trip Production = 1.499 (Population) + 0.111 (Car Ownership) - 322.846 (Schools) + 2.61×10^{-10} (Rental Value)^3 - 48975.692

4.7.3 Trip Attraction Model

Then, the correlation between trip attraction and each socio-economic data was examined.

Table 4.9: Comparison of Correlations (Trip Attraction)

Trip Attraction		X	Ln (X)	Log_{10} (X)	Sin (X)	Cos (X)	X^2	X^3	e^x
Population	Pearson Correlation	.824	.652	.652	-.023	-.052	.740	.685	.000
	Sig. (2-tailed)	.000	.000	.000	.677	.349	.000	.000	1.000
Household	Pearson Correlation	.820	.658	.658	.094	-.065	.749	.701	.000
	Sig. (2-tailed)	.000	.000	.000	.087	.242	.000	.000	1.000
Birth Rate	Pearson Correlation	.387	.339	.339	-.024	.009	.262	.186	-.020
	Sig. (2-tailed)	.000	.000	.000	.658	.875	.000	.001	.724
Death Rate	Pearson Correlation	.649	.560	.560	-.344	.004	.577	.511	.301
	Sig. (2-tailed)	.000	.000	.000	.000	.943	.000	.000	.000
Car Ownership	Pearson Correlation	.481	.209	.209	-.057	.037	.069	.379	.000
	Sig. (2-tailed)	.000	.004	.004	.301	.502	.210	.000	1.000

Trip Attraction		X	Ln (X)	Log_{10} (X)	Sin (X)	Cos (X)	X^2	X^3	e^x
Land Value	Pearson Correlation	.433	.357	.357	.010	-.133	.330	.373	a
	Sig. (2-tailed)	.000	.000	.000	.860	.016	.000	.000	.
Rental Value	Pearson Correlation	.423	.450	.450	-.006	-.021	.435	.498	a
	Sig. (2-tailed)	.000	.000	.000	.920	.706	.000	.000	.
No of Occupants	Pearson Correlation	.835	.633	.633	-.026	.019	.720	.681	.000
	Sig. (2-tailed)	.000	.000	.000	.637	.734	.000	.000	1.000
Total Income	Pearson Correlation	.848	.689	.689	.003	-.074	.738	.692	a
	Sig. (2-tailed)	.000	.000	.000	.962	.188	.000	.000	.
Built-up Area	Pearson Correlation	.226	.278	.278	-.155	.043	.007	-.022	a
	Sig. (2-tailed)	.000	.000	.000	.005	.436	.898	.687	.
Inter Emigration	Pearson Correlation	.662	.462	.462	-.030	.017	.531	.518	.000
	Sig. (2-tailed)	.000	.000	.000	.587	.763	.000	.000	1.000
Outer Emigration	Pearson Correlation	.810	.661	.661	.056	.022	.739	.680	.000
	Sig. (2-tailed)	.000	.000	.000	.307	.696	.000	.000	1.000
Schools	Pearson Correlation	.534	.437	.437	.076	.128	.433	.359	.064
	Sig. (2-tailed)	.000	.000	.000	.168	.021	.000	.000	.249
Residential Area	Pearson Correlation	.051	.082	.082	.029	.007	.041	.019	.039
	Sig. (2-tailed)	.353	.160	.160	.598	.906	.458	.736	.484
Commercial Area	Pearson Correlation	.394	.366	.366	-.084	-.361	.350	.310	.280
	Sig. (2-tailed)	.000	.000	.000	.130	.000	.000	.000	.000
Industry Area	Pearson Correlation	.305	.296	.296	.114	-.294	.258	.219	.222
	Sig. (2-tailed)	.000	.000	.000	.039	.000	.000	.000	.000
a- Cannot be computed because at least one of the variables is constant.									

Same as in the trip production, parameters, which have a higher correlation with the trip attraction, were selected for further analysis.

Table 4.10: Highly Correlated Parameters with Trip Attraction

No	Name if the Attribute	Correlation
1	Population	0.825
2	Household	0.820
3	Death Rate	0.649
4	Car Ownership	0.481
5	Land Value	0.433
6	No of Occupants	0.835
7	Total Income	0.848
8	Inter Emigration	0.662
9	Outer Emigration	0.810
10	Schools	0.534

4.7.3.1 Checking for Multicollinearity

Table 4.11: Correlations between Independent Parameters (Trip Attraction)

		Population	Household	Death rate	Car ownership	Land value	No of occupants	Total income	Inter Emigratio	Outer Emigratio	Schools
Population	Pearson Correlation	1	.996	.836	.512	.374	.913	.907	.770	.908	.528
	Sig. (2-tailed)		.000	.000	.000	.000	.000	.000	.000	.000	.000
Household	Pearson Correlation		1	.832	.505	.392	.918	.906	.766	.904	.522
	Sig. (2-tailed)			.000	.000	.000	.000	.000	.000	.000	.000
Death rate	Pearson Correlation			1	.477	.232	.781	.779	.583	.754	.548
	Sig. (2-tailed)				.000	.000	.000	.000	.000	.000	.000
Car ownership	Pearson Correlation				1	.330	.561	.559	.393	.475	.373
	Sig. (2-tailed)					.000	.000	.000	.000	.000	.000
Land value	Pearson Correlation					1	.361	.384	.307	.370	.202
	Sig. (2-tailed)						.000	.000	.000	.000	.000
No of occupants	Pearson Correlation						1	.974	.543	.858	.572
	Sig. (2-tailed)							.000	.000	.000	.000
Total income	Pearson Correlation							1	.536	.851	.554
	Sig. (2-tailed)								.000	.000	.000
Inter Emigration	Pearson Correlation								1	.813	.771
	Sig. (2-tailed)									.000	.000
Outer Emigration	Pearson Correlation									1	.840
	Sig. (2-tailed)										.000
Schools	Pearson Correlation										1
	Sig. (2-tailed)										

4.7.3.2 Possible Equations

Table 4.12: Model Equations for Different Parameters (Trip Attraction)

Dependent Variable = Trip Attraction				
Model No	**Input Parameter**	**Model Equation**	**R**	**R Square**
1	Population Car Ownership Land Value Schools	1.560(Population) + 0.090(Car_Ownership) + 0.022(Land_Value) - 547.828(Schools) - 45336.974	0.7418	0.5503
2	Household Car Ownership Land Value Schools	6.211(Household) + 0.096(Car_Ownership) + 0.025(Land_Value) - 478.161(Schools) - 49781.445	0.78396	0.5471
3	Death Rate Car Ownership Land Value Inter Emigration	16520.661(Death_Rate) + 0.210(Car_Ownership) + 0.040(Land_Value) + 1.274(Inter_Emigration) -51964.980	0.7197	0.5180
4	Death Rate Car Ownership Land Value Schools	24201.539(Death_Rate) + 0.239(Car_Ownership) + 0.048(Land_Value) + 474.968(Schools) - 62268.280	0.7069	0.4997
5	No of Occupants Car Ownership Land Value Inter Emigration	3.894(No_of_Occupants) - 0.027(Car_Ownership) + 0.027(Land_Value) + 0.329(Inter_Emigration) -47200.432	0.7485	0.5603
6	No of Occupants Car Ownership Land Value Schools	4.387(No_of_Occupants) - 0.028(Car_Ownership) + 0.027(Land_Value) - 139.588(Schools) - 44543.085	0.8494	0.7216
7	Total Income Car Ownership Land Value Inter Emigration	9.56x10^{-5}(Total_Income) - 0.027(Car_Ownership) + 0.023(Land_Value) + 0.314(Inter_Emigration) -40952.618	0.7565	0.5723
8	Total Income Car Ownership Land Value Schools	1.05x10^{-4} (Total_Income) - 0.025(Car_Ownership) + 0.023(Land_Value) - 76.166(Schools) - 38322.648	0.7566	0.5725
9	Outer Emigration Car Ownership Land Value Schools	72.515(Outer_Emigration) + 0.164(Car_Ownership) + 0.014(Land_Value) - 2208.575(Schools) -28002.830	0.7621	0.5809

4.7.3.3 Selected Model (Trip Attraction)

Comparing the R and R square values, following model was selected for the trip production estimates.

Trip Attraction = 4.387 (No of Occupants) - 0.028 (Car Ownership) + 0.027 (Land Value) - 139.588 (Schools) - 44543.085

4.7.4 Trip Interchange Model

After developing the trip production and attraction models, using the models, initially trip productions and attractions for rest of zones were calculated. Then, initially gravity model was applied to find trip interchange values. There was a significant difference of trip interchange values derived from O-D surveys and gravity model. After having a deep literature review, a new version of gravity model called production-attraction constrained gravity model was selected to find the interchange values. The new values and values derived from O-D surveys were matched remarkably. Therefore, as the trip interchange model, the production-attraction constrained gravity model was selected. The model equation is as follows;

$$T_{ij} = \frac{A_i B_j O_i D_j}{d_{ij}^2}$$

T_{ij}= No. of trips from origin i to destination j

O_i= No. of trips beginning from zone i

D_j= No. of trips ending at destination j

A_i= Origin specific correlation factor

B_j= Destination specific correlation factor

d_{ij}= Distance between origin i and destination j

4.8 Model Architecture

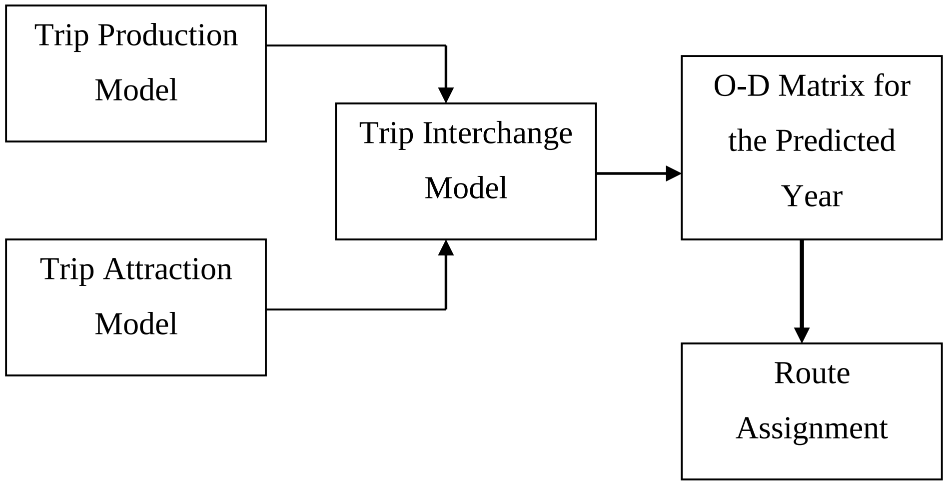


Figure 4.10: Model Architecture

Initially, with the predicted socio-economic data, using the trip production and attraction models, trip production and trip attraction are calculated for DS divisions. Then production-attraction constrained gravity model is used to find the trip interchanges and finally these interchange values are put into the links and nodes by the shortest path analysis.

4.9 Model Validation

Traffic counts in 25 extra links other than the 162 OD locations were done for both directions. With those data, model outputs at same locations were compared using the regression analysis in order to validate the macro model. Here, the regression analysis outputs an equation as follows.

Observed Data = 0.967 Model Output + 0.08 (with R value of 0.876 and R square of 0.774)

CHAPTER 05: MICRO MODEL

5.1 Introduction

The macro model was prepared covering whole Sri Lanka earlier to tackle the inter trips, which has taken the DS divisions as TAZs (see Chapter 4) has taken only the A and B class roads, and as a result of that, it predicts traffic in A and B class roads only. Further, in order to the easiness of analysis, in this macro model, it has been assumed that all the trips are generated and attracted within the one place of a DS division. As mentioned on earlier chapters, data used for algorithms are aggregate based and very few parameters have been considered in the macro model prepared for Sri Lanka, which is the usual appearance in most of macro-models. But, relevant authorities look for implementing most of micro-models' outputs such widening roads, constructing new roads, changing signal timing, restricting the new developments and much more. Further, local area networks are governed by the local governments, who have less investment capacities and lack of technical know-how. Therefore, it is not acceptable to apply macro-model's decisions to the micro-level transport planning and this is true for the Sri Lankan situation as well. Further, most of the available micro-level (intra-city) travel demand models are from developed countries and based on a particular city. Thus, it is not practical and accurate to apply those available micro-models to Sri Lankan cities, which have wholly different travel patterns and development trends. Therefore, preparation of micro models for Sri Lanka's cities is a timely need and careful analysis is compulsory here as being the first attempt in Sri Lanka.

5.2 Microsimulation Approach

Microsimulation models are disaggregate and dynamic in nature, offering effective and practical tools for the representation of complex travel behavior, and are thought to be the most suitable models for local areas (Wu el al, 2003). Advantages of microsimulation include the ability to tabulate impacts for subgroups of the population (for example, low income or elderly), the capability of explicitly modeling realistic travel behavior patterns such as trip chaining and activity scheduling, and the ability to better reflect heterogeneity (and segmentation). Also important is that while aggregate applications have aggregation bias (error induced by applying the model based on average characteristics of the population), a microsimulation approach does not have aggregation bias. The most advanced type of spatial microsimulation models are activity-based travel models (Wegener, 2011). Activity-based travel demand microsimulation models are based on the notion that travel is a derived demand from the need to pursue activities that are scattered in time and space. But, it can be seen that very few microscopic urban travel and land use models have become operational. There are practical reasons for this: the data requirements and computing times of these models tend to be enormous.

5.3 Case Study

In order to make use the macro model outputs correctly, the study area of the micro model should be either DS level based or collections of two or few DS divisions as macro model takes the DS divisions as TAZs. Having looked on the importance and comprised with all kinds of transport and land use interactions, Colombo Divisional Secretariat Division (CDSD) is selected for the micro-model. CDSD covers an area of 18 km^2. CDSD is situated in the Colombo District and Western Province. Further, CDSD has 35 GN divisions.

CDSD has the most complex interaction between transport and land use in the western region as well as in the whole country. This situation is mainly backed by the Colombo sea port, which is the Sri Lanka's main sea port. It creates lots of activities, which use different type of transport services and mainly Colombo sea port brings and sends lots of containers daily, making huge congestion around the port. Moreover, it is further reinforced by Sri Lanka's main railway station and the main bus station situated inside the CDSD. The main commercial market, Pettah Market, is also in the CDSD. Other than that lot of administrative and commercial offices can be seen. From O-D matrix prepared for the macro-model, it can be proved that CDSD is the highest trip attractor comparing to all DS divisions in Sri Lanka.

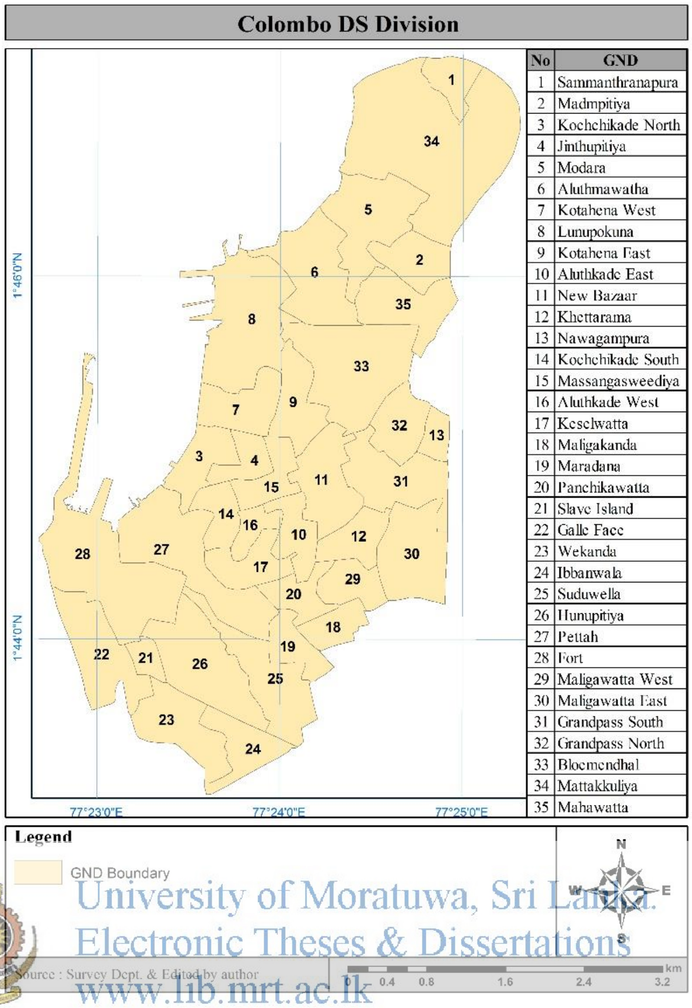


Figure 5.1: The Map of Colombo DS Division

Although CDSD has the highest mix of activities, CDSD is centered to the fairly same DSDs, namely Wattala, Kelaniya, Kolonnawa and Thimbirigasyaya, which have high density mix of activities. Following table proves that CDSD is not only the highest trip attractor, it also a comparatively higher trip generator in the region.

Table 5.1: Comparison of Population and Household Units with adjacent DS Divisions

DS Division	Population	No. of Household Units
Colombo	313, 409	65,343
Wattala	174,336	42,297
Kelaniya	134,693	32,584
Kolonnawa	190,817	44,536
Thimbirigasyaya	236,983	52,285

Table 5.2: Number of population and household units by GND in the Colombo DSD

GN Division	Population	No. of Household Units	Average Household Size
Sammanthranapura	7,787	1,695	4.6
Mattakkuliya	27,776	6,149	4.5
Modara	17,702	3,896	4.5
Madampitiya	12,915	2,812	4.6
Mahawatta	8,758	1,858	4.7
Aluthmawatha	13,455	3,154	4.3
Lunupokuna	12,088	2,782	4.3
Bloemendhal	13,752	3,205	4.3
Kotahena East	6,391	1,604	4.0
Kotahena West	9,171	2,099	4.4
Kochchikade North	9,270	1,843	5.0
Jinthupitiya	7,672	1,582	4.8
Masangasweediya	8,469	1,513	5.6
New Bazaar	13,235	2,483	5.3
Grandpass South	17,546	3,529	5.0
Grandpass North	8,798	1,670	5.3
Nawagampura	6,773	1,446	4.7
Maligawatta East	11,477	2,172	5.3
Khettarama	13,638	2,643	5.2
Aluthkade East	10,037	1,696	5.9
Aluthkade West	7,476	1,253	6.0
Kochchikade South	7,702	1,453	5.3
Pettah	1,749	324	5.4
Fort	653	112	5.8
Galle Face	3,728	727	5.1
Slave Island	3,783	695	5.4
Hunupitiya	6,895	1,365	5.1
Suduwella	3,839	796	4.8
Keselwatta	7,119	1,392	5.1
Panchikawatta	8,420	1,708	4.9
Maligawatta West	8,893	1,811	4.9
Maligakanda	8,068	1,418	5.7
Maradana	4,548	930	4.9
Ibbanwala	1,913	473	4.0
Wekanda	1,913	1,354	1.4

CDSD has high density of road network and comparing to the A and B class roads, the higher number of C, D class roads and minor roads can be seen.

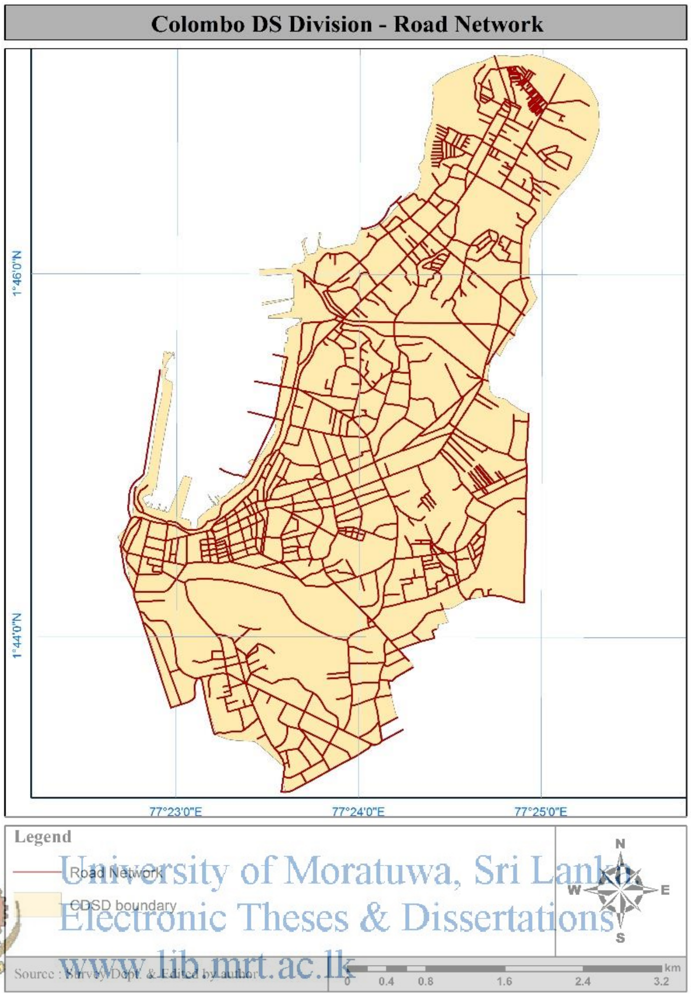


Figure 5.2: The Road Network of Colombo DS Division

5.4 Modeling Process

In order to decide the modeling process of micro model, it is better to have a look on outputs and how those have been generated. Mainly, the macro-model totally cares about particular DS division's interrelationships with all other DS divisions basically in the means of inter-zonal trips. Further, it also gives how these inter-zonal trips have been assigned to the A and B class roads within DS division. This paves the way for micro model of particular DS division to concentrate only on the intra-zonal trips in the DS division. Moreover, the macro model gives some sort of understanding of the local travel pattern in the DS division by giving a figure for intra-trips, which come in 34 categories. The main problem behind the intra-trips generated by the macro-model is that, it is doubtful whether the counting locations used for O-D surveys in the macro model tackle all intra-zonal trips, although it is accurate in the macro model, and those could have not been assigned to the road network. This is happening as there are not enough counting locations and it is assumed that all trips are generated and attracted in one place within the DS division. Here, number of intra-trips from macro-model can be taken as the basis, which needs to be revised.

For the revision, as mentioned above, household surveys were utilized. Household surveys gave the detailed travel patterns of household units. Here, all the external trips were neglected, as macro model has estimated those correctly and fed to the micro model. From the household surveys, GN division basis, travel patterns of households are available. Further, railway passenger O-D surveys were carried out at selected railway stations as macro model does not consider rail trips, where it is not great factor at the macro level but it has a great influence to number of intra-zonal trips occurring inside the DS division. All intra-zonal trips comprise mainly work trips, work associated trips, educational trips, education associated trips, business trips, social trips and recreational trips. These travel patterns further consist with temporal and spatial dimensions as well.

5.4.1 Preparation of Land Use Map

In order to comprehend the travel behavior, it is necessary to have a detailed understanding of trip generators and attractors. Moreover, it seems that railway lands and other utilities such as bus stations, bus halts, three-wheeler stations, etc. also occupy considerable area of lands in the study area. To a certain extent railway lands can be identified as trip starting points to the micro model as the O-D matrix prepared for the macro model did not consider train trips. Further, in order to make forecasts, information of developable and protective lands is required. Other than that, parking areas are another important land use aspect especially in CDSD, where parking along the roads is severely prohibited. People who travel with their own vehicles tend to park the vehicle at nearest parking area to the desired location and travel the rest mostly by the foot or infrequently by the hired three-wheeler. In such a way, parking areas can be identified as a trip starting point and also a trip ending point. Therefore, comprehensive land use map is the identical explanation for this. From the field surveys, diverse types of land uses were identified. While taking all important uses and to facilitate analysis, major types of land uses were identified as follows.

Table 5.3: Selected Land Use Types

Trip Attractors	Work based	Institutional based	Administration Offices, Other Institutions, Whole Sale and Retail Shops, Banking and Allied Places
		Industry based	Harbor, Industries, Stores and Warehouses, Automobile Repairs and Workshops
	Social		Hospitals and other Medical Institutions, Religious, Community Organizations, Socio-Cultural Places
	Educational		Educational Places
	Recreational		Beach, Cinemas & Amusements, Hotels and Guest Houses, Parks & Playgrounds
	Business		Whole Sale and Retail Shops, Banking & Allied Places, Automobile Repairs and Workshops, Harbor, Industries, Stores and Warehouses
Trip Generators	Residential Lands, Apartments, Quarters, Slums and Shanties		
Developable Lands	Filled Lands, Under Construction Lands, Vacant Buildings, Vacant Lands		
Protective Lands	Inland Wetlands, Urban Forest, Water Bodies		
Other	Parking Areas, Utilities, Railway Lands		

Finally a detailed land use map comprised with above categories was created with the help of field surveys, satellite images and Google images.

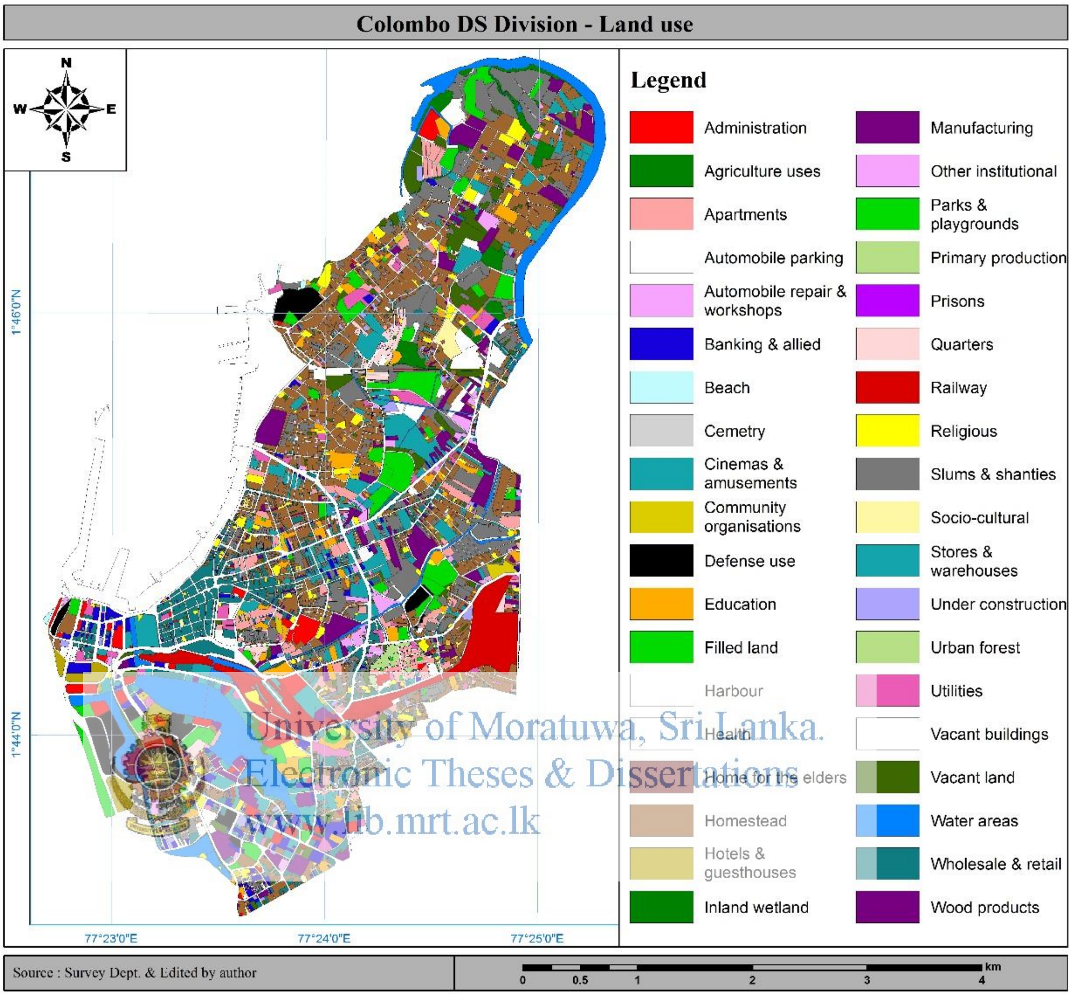


Figure 5.3: The Land Use Map of Colombo DS Division

5.4.2 Preparation of Transport Network Maps

Two types of transport networks are significant in this regard. Those are road network and railway network. In order to discover the number of trips along the links correctly, recognition of all roads used by vehicles is a necessity. Otherwise, outputs will show that some links are congested, when actually it is not. The road network was identified as nodes and links. Using the Google images, satellite images, available ESRI shape files and field visits, a map of road network was prepared including all nodes and links in the CDSD. Further, two attribute tables were prepared separately for nodes and links.

Table 5.4: Attributes for nodes and links in Colombo DS Division

Nodes' Attribute Table Parameters	**Links' Attribute Table Parameters**
Name	Length
Number of ways	Number of lanes
Connecting links	Starting node
	Ending node
	One way or not

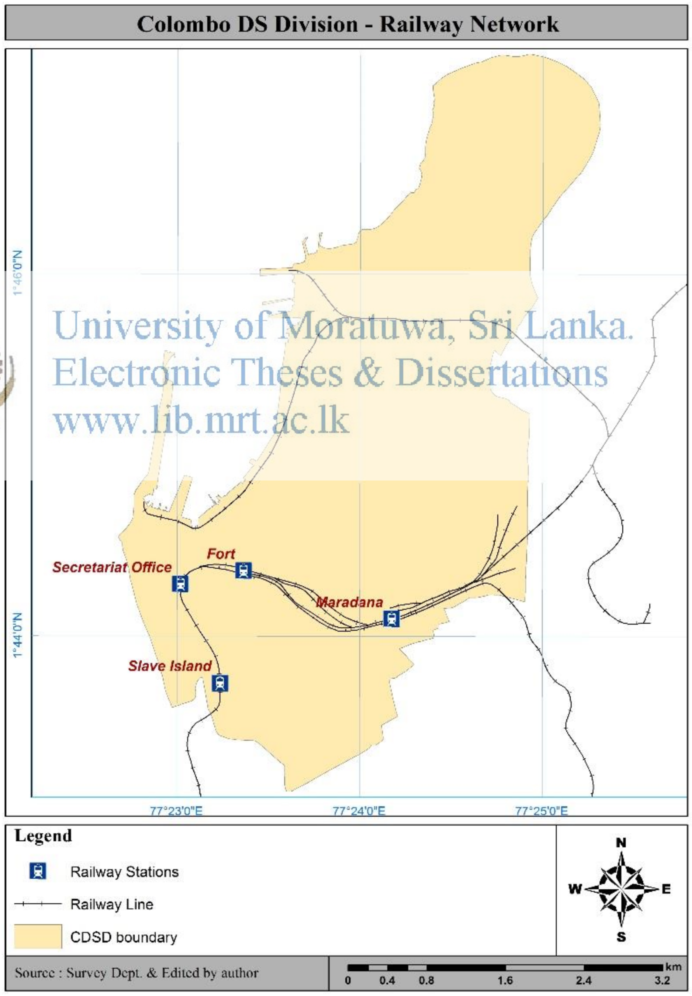


Figure 5.4: Map of Railway Network of Colombo DS Division

Using the Google images and available ESRI shape files, the map of railway network including the railway stations inside the CDSD was prepared.

5.4.3 Preparation of Building Map

The land use map prepared for the CDSD is comprised of 5257 land plots on above mentioned land use types. Each land plot was created connecting neighboring buildings and lands in similar land use type. Also it can be seen that some land parcels occupy a large amount of buildings. With the careful examination the Google images in the study area, it can be seen that buildings within the same land parcels even should be accessed by different routes and there are some roads within the land parcels as well. Therefore, it will be a great drawback to the microsimulation approach, which is to understand the travel behavior to maximum accuracy, if one location of the particular land parcel is considered as either trip staring point or ending point of all buildings within the land parcel. Therefore, although land use map is a good foundation, the building wise examination is required for the microsimulation approach.

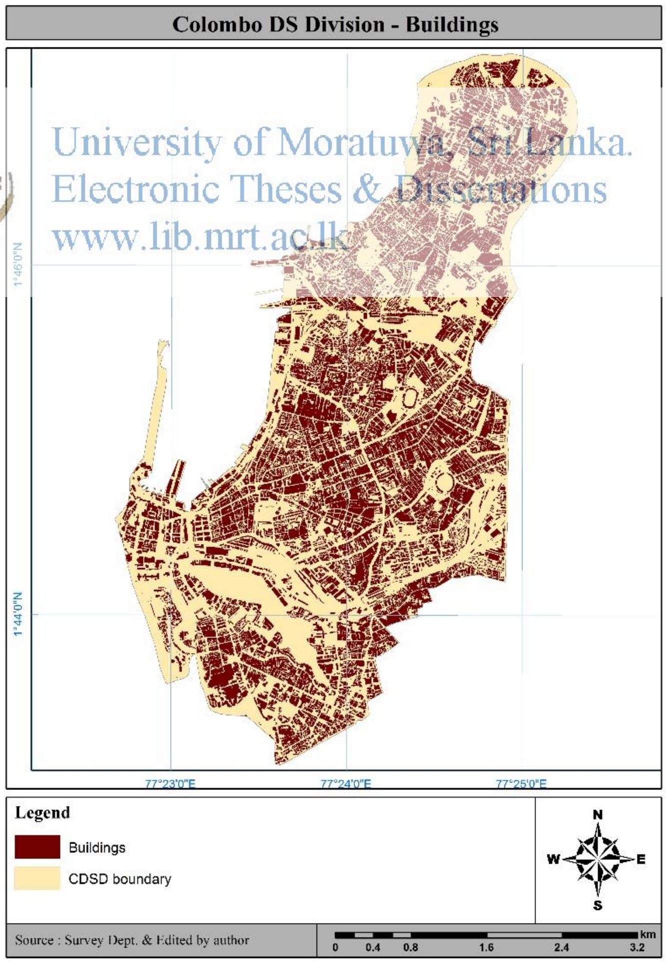


Figure 5.5: Building Map of Colombo DS Division

In this context, a building map for the whole CDSD was prepared by using Google images, satellite images and field surveys. Here, buildings were categorized as same as the land use categorization.

5.4.4 Household Survey

100 household units were surveyed as the pilot survey in order to identify the travel pattern. Other objectives were to design the survey form correctly, identify the locations to carry out the surveys and identify the solutions to usual problems encountered in doing household interviews. (See Annex 06)

Table 5.5: Household Survey Locations and Sample Sizes

GN Division	No. of Household Units	Sample Size
Sammanthranapura	1,695	52
Mattakkuliya	6,149	188
Modara	3,896	119
Madampitiya	2,812	86
Mahawatta	1,858	57
Aluthmawatha	3,154	97
Lunupokuna	2,782	85
Bloemendhal	3,205	98
Kotahena East	1,604	49
Kotahena West	2,099	64
Kochchikade North	1,843	56
Jinthupitiya	1,582	48
Masangasweediya	1,513	46
New Bazaar	2,483	76
Grandpass South	3,529	108
Grandpass North	1,670	51
Nawagampura	1,446	44
Maligawatta East	2,172	66
Khettarama	2,643	81
Aluthkade East	1,696	52
Aluthkade West	1,253	38
Kochchikade South	1,453	44
Pettah	324	9
Fort	112	3
Galle Face	727	22

Slave Island	695	21
Hunupitiya	1,365	42
Suduwella	796	24
Keselwatta	1,392	43
Panchikawatta	1,708	52
Maligawatta West	1,811	55
Maligakanda	1,418	43
Maradana	930	28
Ibbanwala	473	14
Wekanda	1,354	41

Several observations could be made from the pilot survey.

- There is a vast similarity of trips within a GN division.
- Basically, trips can be identified in three ways namely week-day trips, week-day associated trips and weekend trips.
- Trips are originating from homes and attracted to work, education, business, social and recreational land uses.
- It seems that associated trips of business, social and recreational trips are negligible.
- Considerable amount of associated trips can be seen from home based work trips and home based educational trips. As examples for some associated trips it can be seen that before, in between and after the working times, some people tend to go business such as shopping and students participate for tuition classes after schooling. Also there are very few associated trips occurred in weekend trips.
- All week-day trips, week-day associated trips and weekend trips, taking the GN division names as the destination ends of trips is the most appropriate way as it is not practical to plot the addresses.

Some decisions were made using the information collected from the pilot survey.

Table 5.6: Trip Types

Week-Day Trips	Week-Day Associated Trips	Weekend Trips
• All trips from Monday to Friday • All trips begin from home. • Trips will be categorized into work, education, business, social and recreational accordingly to the purpose. • GN division name will be taken as the destination. • It can be seen that households with same physical features and socio-demographic details have similar travel pattern.	• All associated trips from work and educational trips happening from Monday to Friday • Trips will be begun either from home, working place or educational place. • Three types of associated work trips can be seen namely before, in-between and after working times while associated educational trips comes in two aspects only, which are before and after schooling times. • Trips will be categorized into work, education, business, social and recreational accordingly to the purpose. • Same GN division name will be taken as the destination. • It is so hard to identify any similarity on travel pattern on household basis. But it seems, there is a similarity in GN wise.	• All trips from Saturday and Sunday • All trips begin from home. • Trips will be categorized into work, education, business, social and recreational accordingly to the purpose. • GN division name will be taken as the destination. • It is so hard to identify any similarity on travel pattern on household basis. But it seems, there is a similarity in GN wise.

Household travel survey form is prepared by using both the analysis of pilot survey and land use types identified under the land use map. The survey form designed for the household surveys is attached in the appendix.

It was decided to carry out the interviews in GN division level. The main reason was that GN level is the lowest geographical level that has the number of household units and population data from the census. Sample sizes and sample selections are important concepts to consider before starting the household travel surveys (Mathew and Rao, 2006). While representing the true value in the population, also the cost factor, time and availability of human resources were major concerns for deciding sample sizes and sample selections. While achieving the confidence level and confidence interval 99% and 3 respectively, sample size of 1798 was decided to 65,343 household units in CDSD. This sample size was distributed to GN divisions proportionally to the number of household units with few adjustments for Pettah and Fort GN divisions. The sample size selected for each GN division is shown below. Random sampling technique was used to select samples with a given GN division. Data is collected through face-to-face interviews and this method ensured high quality data, maximizes response rates and ensures a good temporal spread. Field staff interviewed each householder on the details of trips made in the whole day. Further, physical features and detailed socio-demographic information as explained below were also collected on household basis.

5.4.4.1 Household Data Analysis

Analysis was carried out for week-day trips, week-day associated trips and finally for weekend trips separately.

5.4.4.1.1 Weekday's Main Trips

Similarities can be seen in the travel patterns among the household units in each GN division. Further, there is a vast compatibility between these similarities and households' physical features and socio-demographic details. Physical features comprise with main construction material of the house (including the boundary wall), land area and type of the access road (whether the A, B, C, D class road, minor road or private road) and socio-demographic details consist with household size, number of private vehicles, family income and number of economically active persons.

Accordingly to the survey results, number of household types is identified in each GN division.

Table 5.7: GN Divisions and Number of Household Types

GN Division	Number of Household Types
Sammanthranapura	5
Mattakkuliya	10
Modara	6
Madampitiya	5
Mahawatta	5
Aluthmawatha	6
Lunupokuna	6
Bloemendhal	6
Kotahena East	4
Kotahena West	5
Kochchikade North	5
Jinthupitiya	4
Masangasweediya	4
New Bazaar	6
Grandpass South	8
Grandpass North	4
Nawagampura	4
Maligawatta East	5
Khettarama	6
Aluthkade East	5
Aluthkade West	4
Kochchikade South	4
Pettah	3
Fort	5
Galle Face	3
Slave Island	3
Hunupitiya	3
Suduwella	3
Keselwatta	4
Panchikawatta	5
Maligawatta West	5
Maligakanda	4
Maradana	3
Ibbanwala	3
Wekanda	4

Travel patterns of household types in each GN division are attached in the Annex 07

5.4.4.1.2 Assigning Week-Day Trips

Through ArcGIS, each building finds the closest node and it can be either trip starting point, trip ending point. It is assumed that all the trips will use the shortest route available and further all routes are capable of handling all transport modes.

Initially all the residential buildings (homesteads, apartments, quarters, slums and shanties) in each GN division were categorized into the selected household types. This step was supported by many number of field visits. In association with travel patterns of household types in each GN division, trip generation step can be done and closest nodes get the trips to be distributed. All the trips on nodes know the destination GN division, trip purpose, transport mode and trip starting time from both ends. Then trips will be distributed according to this information.

As an example, if a household of a Mahawatta GN division has 2 work trips for administrative offices in the Fort GN division, then these two trips will be distributed to all the administrative buildings proportionally to the extents of land of administrative buildings in Fort GN division through shortest paths. Further, a household of New Bazaar has 1 educational trip to Lunupokuna GN division then, similarly, this trip will be distributed in proportionally to all education buildings by shortest paths in Lunupokuna GN division. This process continues until trips of all households in all GN divisions are distributed. Same as trip generation, all these trips receive by the closest nodes of particular trip attracting buildings. The return trips begin with trip attracting buildings and come to particular home lands back, where each trip here knows what is the home land that trip begins with. Further, respective percentages should be deducted in work and educational trips in order to accommodate work and educational associated trips respectively.

5.4.4.1.3 Week-Day Associated Trips

Here, associated trips occur in work trips and educational trips. Not like week-day trips, associated trips come as aggregate based in GN wise. Further, associated work trips can be categorized in three aspects namely before staring the work trip, in between the work trip and finally after the work trip. As mentioned above, education associated trips occur in two ways, before the educational trip and after the educational trip.

Associated trips occurred in between work trips do not affect to the work trips but others affect the process. Same as, before and after education associated trips affect to the normal process of educational trips. Therefore, percentages of before and after associated trips should be deducted from departure trips and arrival trips respectively in both work and educational trips.

Associated work trip and educational trip tables of GN divisions are attached in appendix. All associated trips come with firstly whether the trip is going outside the CDSD or not, in and out trip starting times, indication of whether the before, in-between and after the original trip, transport mode and the trip purpose.

Table 5.8: Associated Trip Types

Time of happening	**Work associated trips**	**Education associated trips**
Before	Home to Desired Location and Desired Location to Working Place	Home to Desired Location and Desired Location to Educational Place
In-between	Working Place to Desired Location and Desired Location to Working Place	
After	Working Place to Desired Location and Desired Location to Home	Educational Place to Desired Location and Desired Location to Home

GN to GN level analysis is done here. It can be identified that what are working locations and educational places of household members of a particular GN division and amount of trip attracted for those places. For associated trip analysis, identified portion of trips are distributed to same GN division basis to the desired locations on shortest paths.

5.4.4.1.4 Finding the Desired Location

Number of work and education associated trips generated by each home land (one housing type or collection of several housing types) and portions of before, in-between and after work associated trips (only before and after in educational trips) are known here. All these proportions are equal to all household units in a particular GN division. First and foremost these portions are applied to the each home land. Same process is followed to the before and after associated trips in both work trips and educational trips. Further, a difference approach is in action for the in-between work associated trips.

5.4.4.1.5 Before Associated Trips (for Work and Educational Trips)

All trips are begun from households. Here, trips are distributed to desired locations initially as per survey results. As an example, in Sammanthapura, percentage of work associated trips is 6% from the work trips and further, before work associated trips occurs 32% from all work associated trips. Out of this 60%, 55% of trips are business trips. Then, these business trips (before work associated business trips) are distributed to all business buildings situated in the same GN division proportionally to the extent of the areas of business buildings. Then, these trips are put to the time slots and transport modes according to the survey results. In Sammanthapura, from before associated trips, out of this 20%, 35% are educational trips. Same way, particular portion of trips from each household is distributed to all the educational buildings fallen in the same GN division lied within the DSD proportionally to the extents of lands of educational buildings with time and the transport mode. Here, the return trips are going to the working place. It is well known that where the before associated trips are end up in a particular GN division. As knowing what are the original working locations of households of the particular GN division, return trips are easily distributed to these working locations in the same way that main work trips are distributed considering the destination GN division, time and transport mode from the desired locations. Equally same process is applied to the before education associated trips. (See Annex 08)

5.4.4.1.6 After Associated Trips (for Work and Educational Trips)

GN level, it is known where it’s working trips and educational trips are end up. Here, trips begin from either working places or educational places and end up with homes. Respective proportions can be applied to those trips in order to find out the amount of after associated trips for both educational and work trips. As an example, Mattakkuliya

GN division comes with 7% of education associated trips out of educational trips and further, out of this 7%, 70% are after associated trips. Therefore, trip ending points can be easily determined in the same manner as depicted in before associated trips. These ending points are the beginning points for the return trips. Also destination home lands can be traced easily here. Therefore, these trips are distributed to those locations with the time and transport mode.

5.4.4.1.7 In-Between Associated Trips (Only for Work Trips)

Here as well, as knowing the destination locations of the work trips of particular GN divisions, proportions can be applied in accordance found from household travel surveys. From the same analysis way, with the purpose, desired locations of trips can be easily found. Further, ways of return trips can be traced as knowing both beginning points and ending points of the previous trips, which are the same ends but in reverse. Finally, time slots and transport modes are applied for both ways. (See Annex 09)

5.4.4.1.8 Weekend Trips

Similarity cannot be harnessed between the household types selected and weekend travel patterns. But, it appears that households in the same GN division tend to select similar locations for weekend trips. Therefore, analysis was done in GN level. The survey form used is attached in the Annex 10.

Here, number of trips in each type is distributed among all household units equally at first. Then, it is known that what the destination GN divisions of these trips are. Finally, trips are distributed according to the extents of building areas of particular type as same as week-day trips analysis. (See Annex 11)

5.4.5 Rail Passenger O-D Survey

At present, land transportation of Sri Lanka consists only with road network and railway network. In the macro model, road transport was only considered as it accounts for about 93% of the land transport in Sri Lanka. But, it can be seen that considerable amount of people, who are living outside the CDSD, are coming from trains to railway stations situated inside the CDSD and from there, they use road transportation to access the desired locations inside and outside the CDSD creating considerable amount of traffic on roads. Therefore, railway stations can be taken as large trip generation places in the micro-model for CDSD.

In order to find the travel pattern, railway passenger O-D surveys were carried out at two railway stations situated inside the CDSD. Here, 50 railway passengers were interviewed in each hour beginning from 5 am to 10 pm mainly about whether the inside or outside trip and if an inside trip, then what is the destination GN division, trip purpose, transport mode and time of starting the return trip and if an outside trip, what is the node that particular trip is going out, time that return trip back to particular node and transport modes used.

Finally, following the same trip distribution method as distributing week-day trips, trips started from all railway stations within the CDSD were distributed accordingly to the survey results. (See Annex 12 and Annex 13 for the survey form and the survey analysis respectively)

5.5 Preparation of Final O-D Matrix

In CDSD, 930 nodes can be seen. After assigning trips, each node's trip production and attraction, and the number of trips from one node all other nodes can be determined. Nodes are taken as zones in preparing the O-D matrix. Therefore, O-D matrix could be prepared including the values of trip interchanges. Then, those trips were distributed to the particular links based on the shortest path analysis.

5.6 Model Validation

Here, traffic counts at present situation were collected from 20 links, covering all types of links in the Colombo DS Division area. Then, model outputs and observed data are compared by the regression analysis. The regression analysis outputs an equation as follows.

Output = 0.824 Model Output + 0.21 (with R-value of 0.922 and R-square value of 0.874)

CHAPTER 06: DEVELOPMENT OF SOFTWARE PROGRAM

6.1 Software Architecture of the Transport and Land Use Model

The overall architecture of the transport and land use model has two basic components, a server side component and a client side user interface for rich graphics as illustrated in Figure 6.1.

Figure 6.1: Client Side and Server Side Modes

While the server side map processor is responsible majorly on time consuming map processing tasks, client side user interface is responsible for interacting with the user with rich user graphics. Here, "python" is selected as the server side map processing language while "java" is selected as the client side interface language.

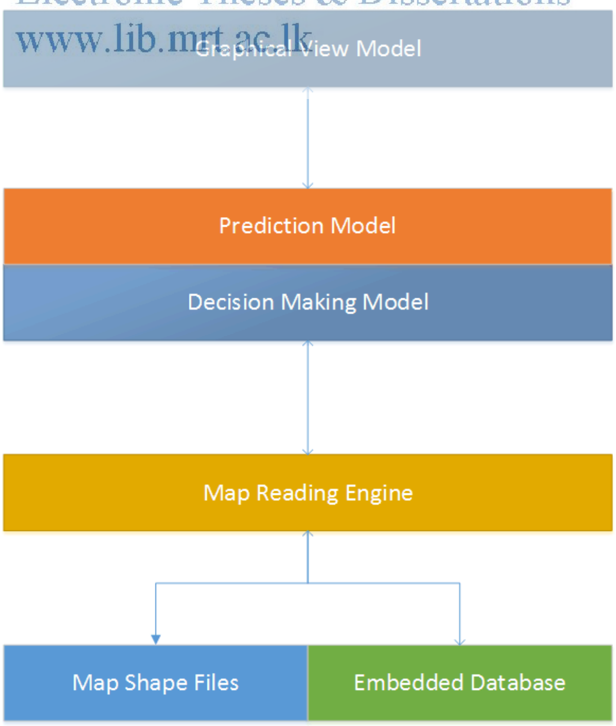


Figure 6.2: Architecture of the User Interface

Figure 6.2 illustrates the architecture of the user interface. The underground data sources for the user interfaces are the map shape files and an embedded database. Map shape files are generated from the server side, which are portions of processed maps while the embedded database contains information on features of maps collected from surveys. “Apache DB” was selected as the database version as it is light weight as well as capable of embedding easily in to a software package. Graphical view model comprises of Java Swing modules, which are rich in user interface designs with easy to use components.

6.2 Functions of the Transport and Land Use Model

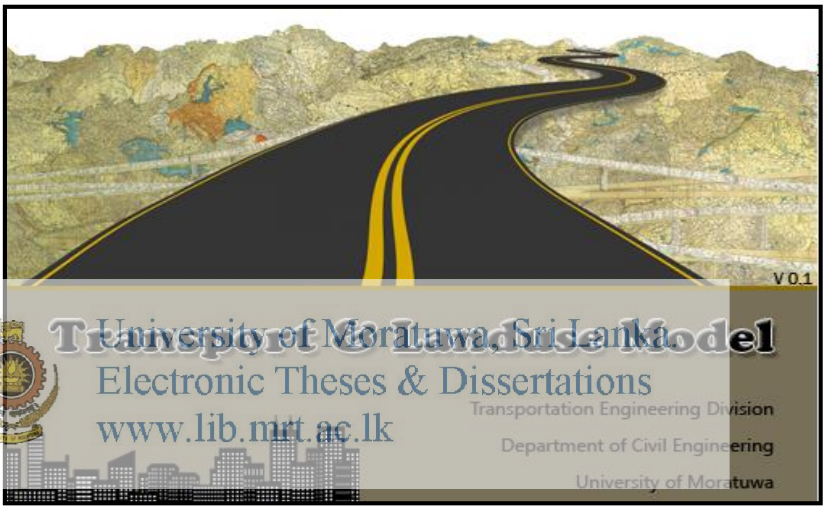


Figure 6.3: Welcome Interface of the Software Program

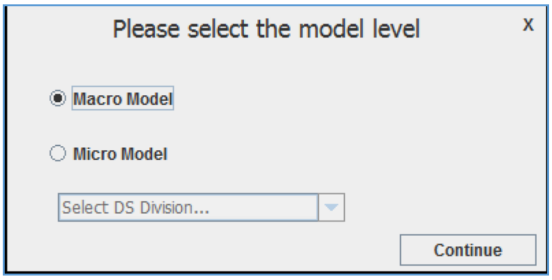


Figure 6.4: Interface of the Model Selection

Figure 6.3 illustrates the welcome interface of the software program. Then, the user is allowed to choose the macro model or micro model as mentioned in figure 6.4. If micro model is selected, then user has to select the particular DS division. Here, the research only has covered the Colombo DS division.

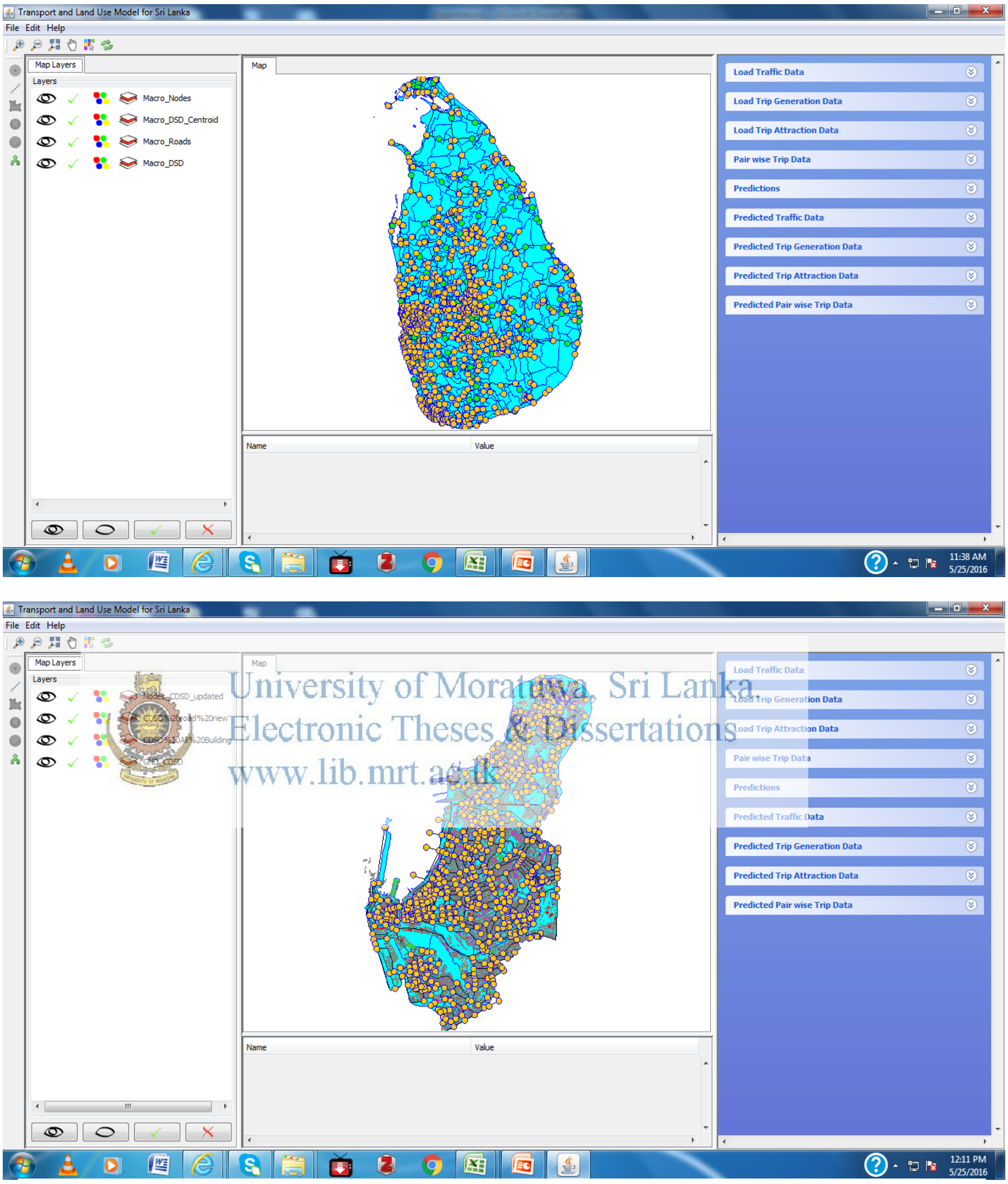


Figure 6.5: Initial Interfaces of Macro and Micro Models

Figure 6.5 illustrates the initial interfaces of macro and micro models. Four shape files, namely road network, centroids, nodes and DS divisions are already opened in the macro model. The micro model is opened with road network, building layer, nodes layer and GN divisions. User has the ability to switch on and off the layers, and zoom in and out layers, for getting a clear understanding of the study area. Further, the software program has facilitated for users to get a full description of each feature under the every shape file as illustrated in the Figure 6.6.

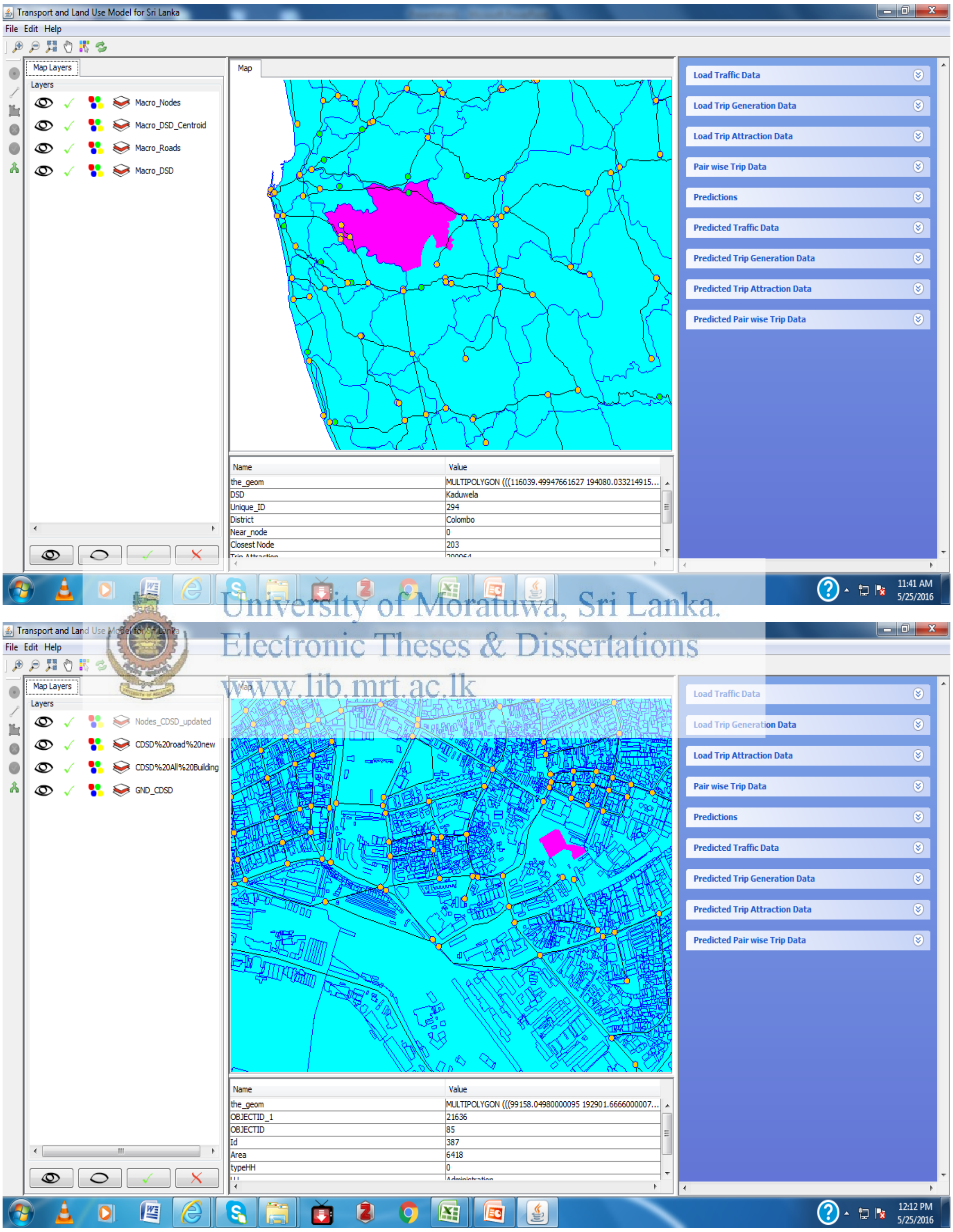


Figure 6.6: Description of the Selected Features

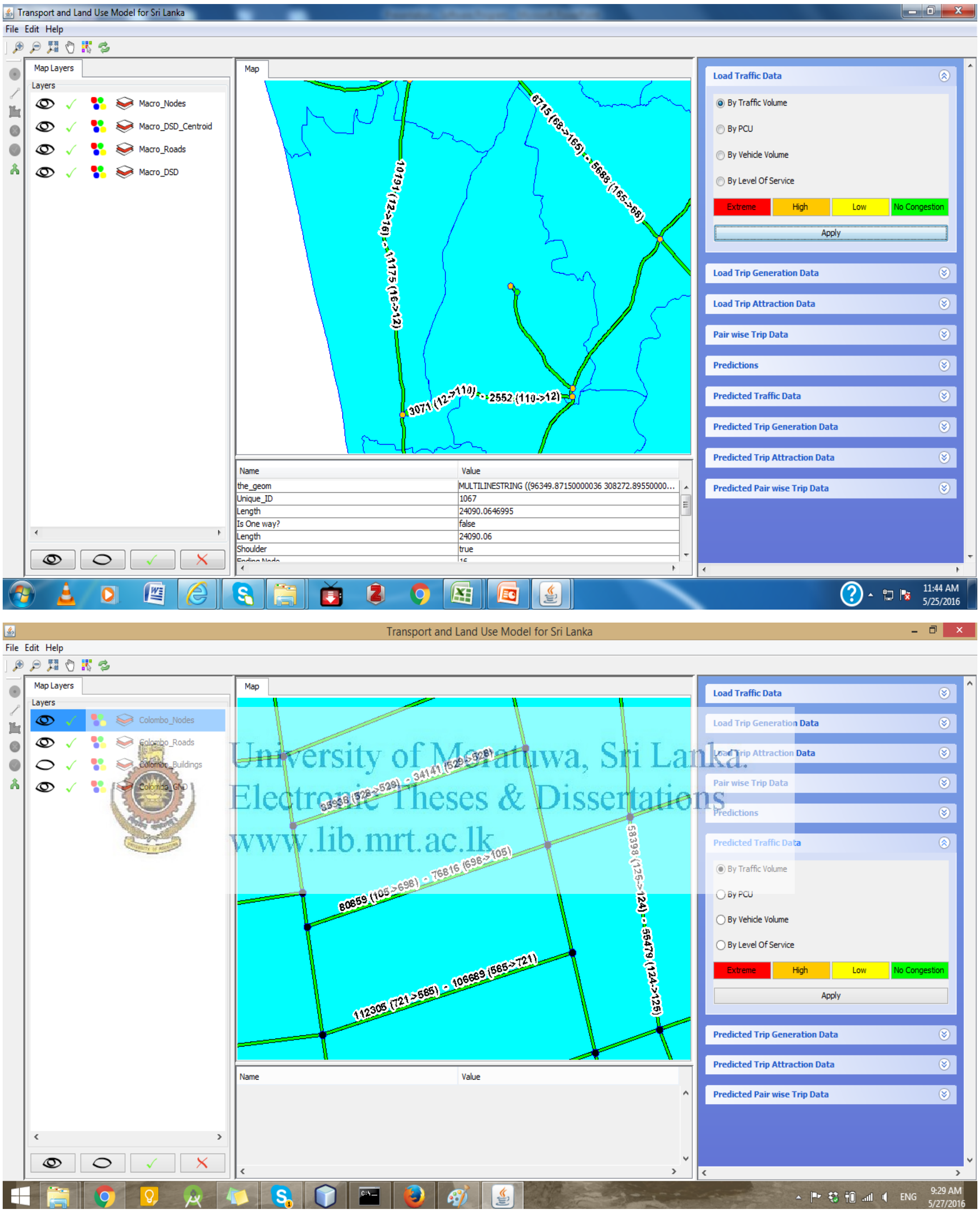


Figure 6.7: Traffic Volumes of Links

As shown in the figure 6.7, traffic volumes in the means of trips, passenger car units and number of vehicles of links for both directions can be shown on top of corresponding links. This can be done for both present and future situations.

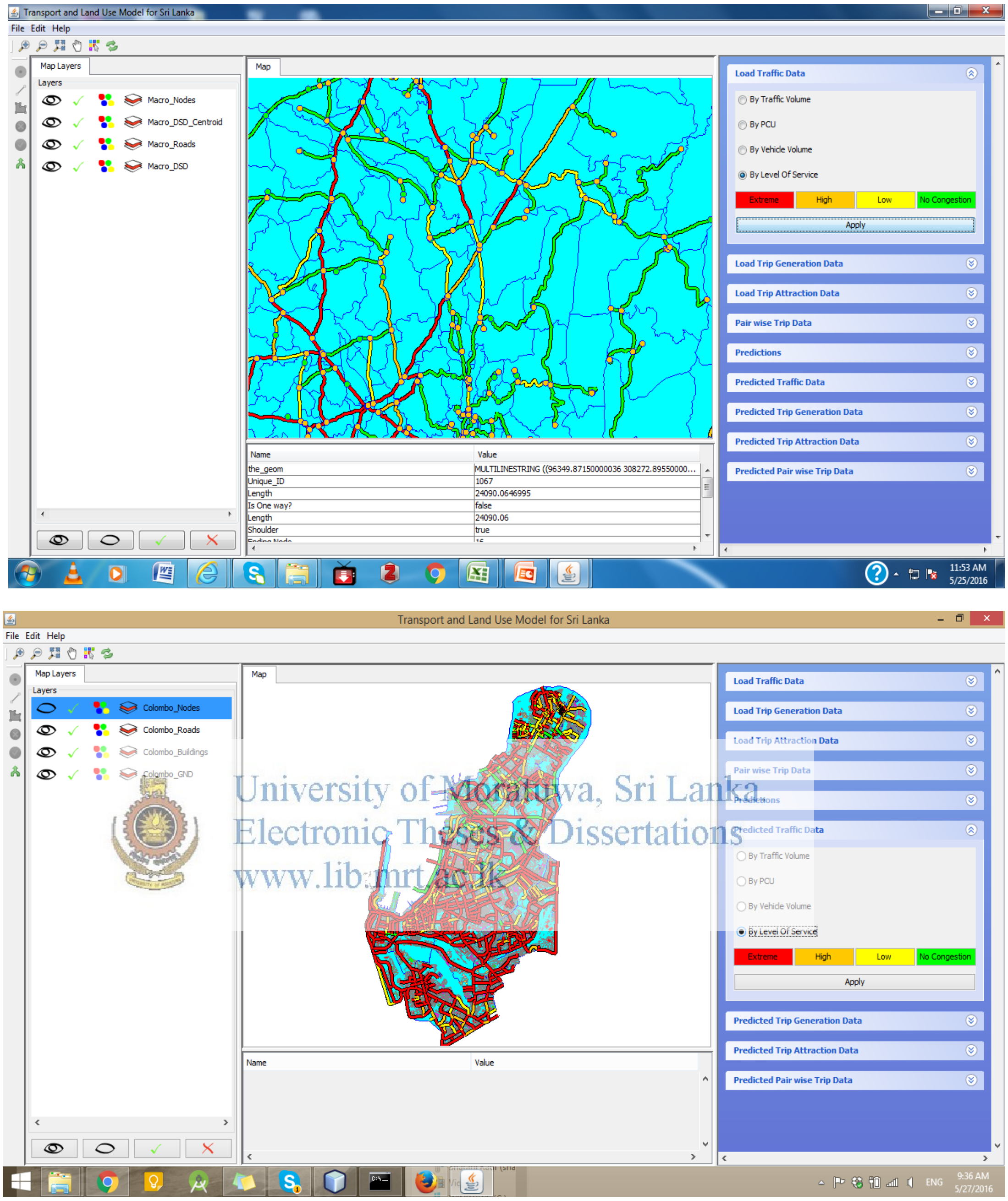


Figure 6.8: Congestion Level of Links

As shown in the figure 6.8, the user can oversee the congestion levels of the links and nodes. This also can be done for both present and future situations.

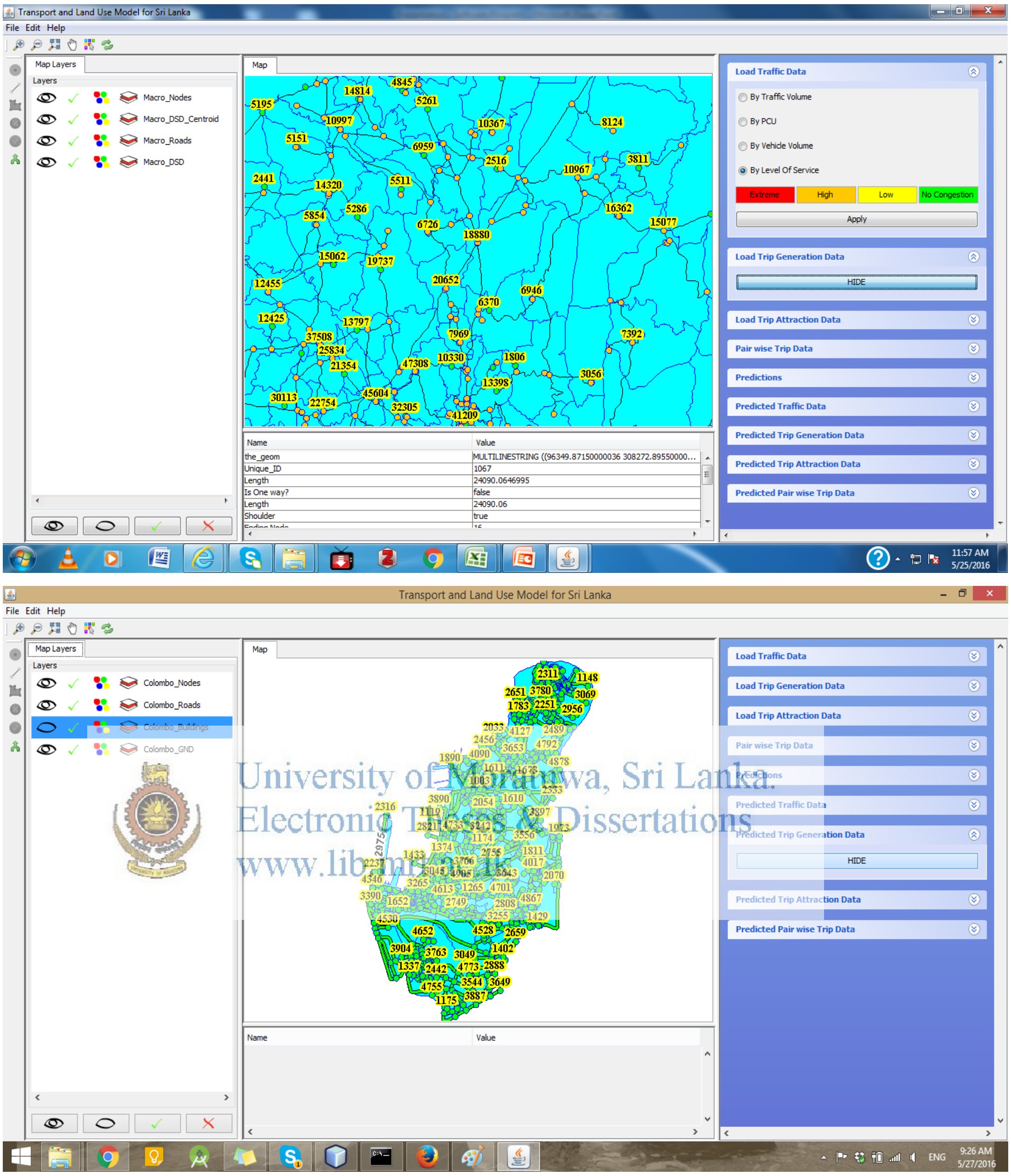


Figure 6.9: Trip Generation and Attraction Volumes

The software program has a function of loading present and future trip generation and attraction data in zone-wise in the macro model and in node-wise in the micro model. Further, trip interchange values between zones can also be taken from the software program.

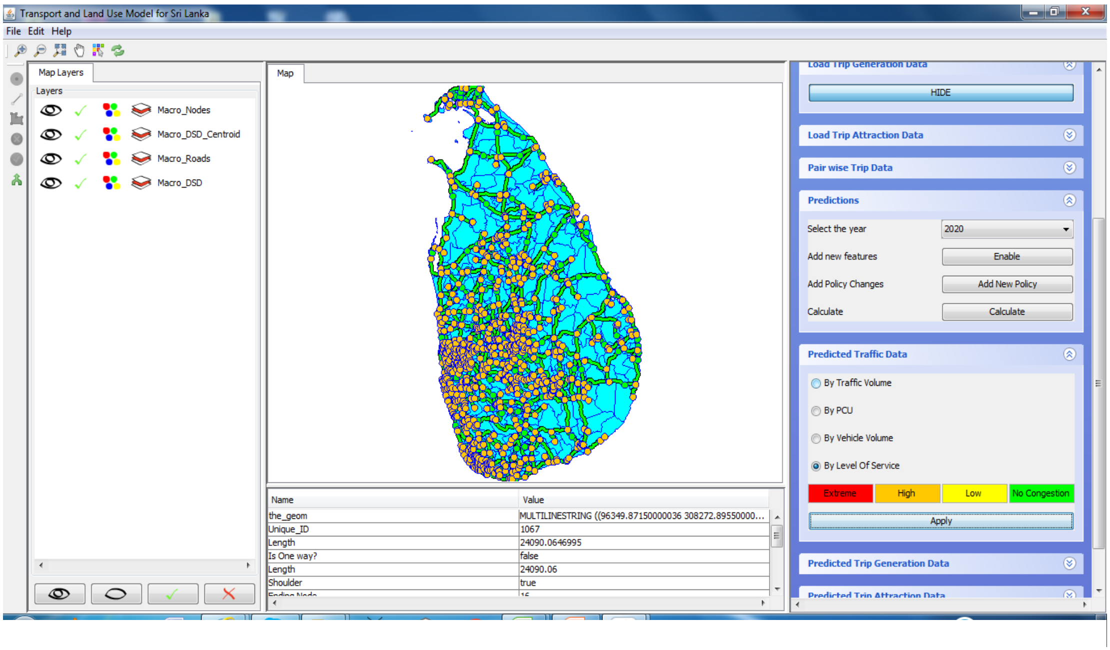


Figure 6.10: Transportation Predictions

Here, users can do the predictions. It is shown in figure 6.10. User needs to carry out several steps as follows before the predictions.

- Select the year
- Add new features – Under the macro model, user can only add new links. As shown in the figure 6.11, user needs to add the features of the proposed links. User can add both buildings and links in the micro model. Required features of the particular building should also be added as shown in the figure 6.12.
- Add policy changes – User can enter values as necessary for independent parameters in the trip production and attraction algorithms in the macro model.

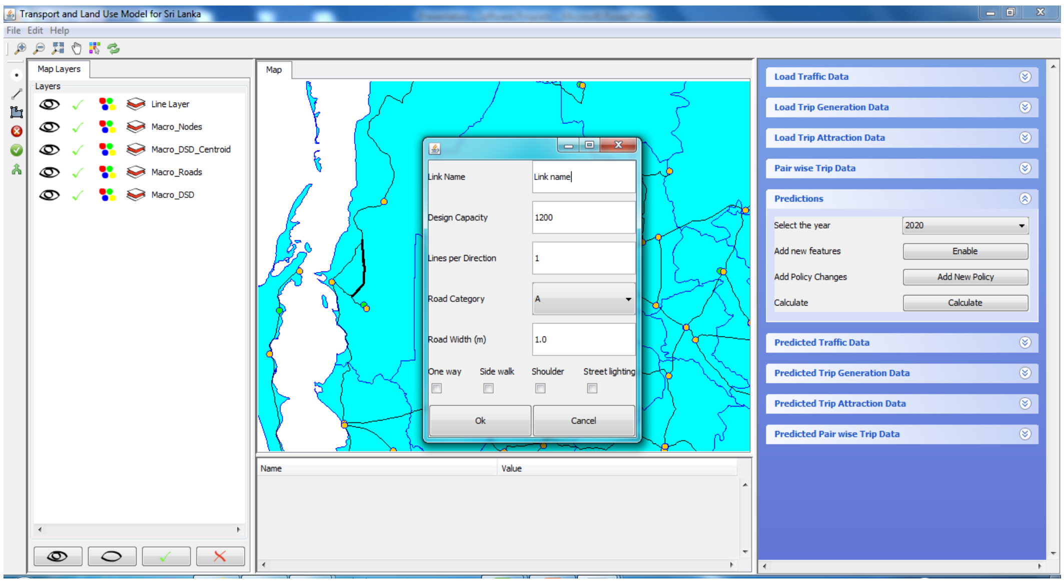


Figure 6.11: Adding new features (Roads)

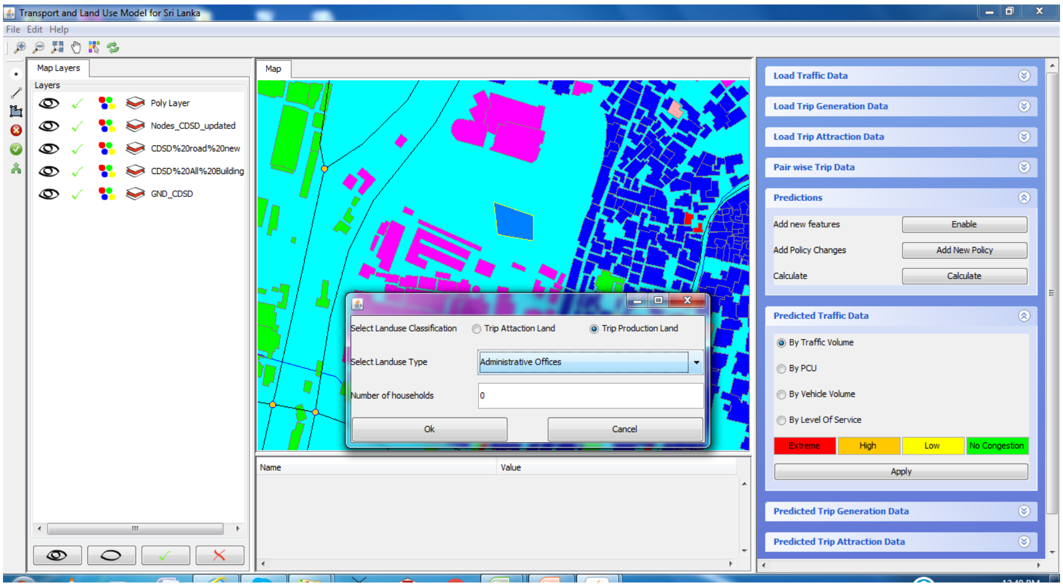


Figure 6.12: Adding new features (Buildings)

CHAPTER 07: CONCLUSION AND CRITICAL EVALUATION

Travel demand estimation is one of the major tasks of transport planners and planners use different techniques to perform it. Here, in the world today, use of models for travel demand estimation has become a fashion. The necessity of integrating the land use aspect for travel demand estimation is well known in the profession. Therefore, many transport and land use models are in operation today. There are significant variations among the models with respect to modeling approaches, modeling techniques, theoretical foundations, dynamics, data requirements and, calibration and validation. Further, most recent models have followed the prospects and eliminated the constraints in all past land use transport models. Thus, existing models provide an excellent background for new developers. Also, present day models were created with conspicuous interactive features allowing users to add and amend the number of inputs and their significance to the model. Using GIS in present day models has paved the way to input or output the spatial related data, which are more explicable than normal numeric or written data. It is remarkable that still most models are from developed countries and, developing countries buy or hire them at a high cost whenever required. But, there is a huge doubt of the accuracy level as many features such as travel behavior, household income, car-ownership, organizational structure etc. are totally different in developing countries comparing to developed nations.

Transport and land use models play an important role not only in the transport and land use planning but also in many planning disciplines such as economic planning, environmental planning, social planning etc. Especially in Sri Lanka, the need of a sophisticated transport and land use model is deeply felt. Although, most decision makers are well aware about the need of accounting the integration between transport and land use, lack of having proper mechanism has kept them away from doing so. Other than the census data, all other data available in Sri Lanka have many shortcomings such as not in the correct format, not available for all locations, no reliable source, high cost in data collection etc. Same situation is prevailing in most of developing countries. These can be regarded as the main reasons for not taking most of other stylish data intensive modeling techniques for model developments.

Preparation of two models for macro and micro levels is a wise decision because of the distinctive nature of the travel behavior. Most of the modeling techniques analyzed under chapter 2 and chapter 3 are very data intensive and, accurate data and vast range of data types are the most dominant factors for determining the accuracy level of the modeling technique here. In Sri Lanka, most of the data required for such techniques are not available in relevant authorities and the data collection could be a great nuisance. In transportation planning, an accurate O-D matrix could be used to generate more and more accurate transport related outputs. According to the literature on hand, the top-down approach explained in the chapter 4, which eliminates both double counting and leaky screen-line problems in O-D survey analysis, can be regarded as the first mechanism to do so in the world. The requirement of high number of costly O-D surveys is the main drawback of the preparation of O-D matrix. But, surveys need to be done only one time, and therefore, considering the Sri Lankan situation, the use of O-D matrix based equations developed with socio-economic data can be taken as the most appropriate modeling technique for the macro model, which covers the whole Sri Lanka. Further, another major advantage is that the O-D matrix prepared from O-D surveys is much closer to the reality and thus planning authorities accept it with little or no arguments.

Activity based approach, which is the most prominent modeling approach in Microsimulation modeling, is now extensively used as the major modeling technique in the present day modeling due the high level of accuracy. But, this data intensive approach is not valid for larger geographical areas as many surveys are required for data collection. Colombo DS division has the highest complexity in terms of transport and land use aspects in Sri Lanka. Therefore, Colombo DS division was selected to the micro level analysis assuming lessons learnt here could solve the most problems in developing a micro model to another geographical location, where the complexity is much lower. Use of the microsimulation modeling approach for the micro-level model paved the way to get more benefits: 1) it is possible to model societal developments, such as new life styles, work patterns and new tendencies in mobility behavior, 2) it is possible to forecast the impacts of innovative policies in the field of travel demand management and transport operation, and 3) it is possible to model the environmental impact of land use and transport policies with the necessary spatial resolution.

Both these models can generate range of information, which are really important to the decision making process. Both models have been developed by open source based programming languages. Later both models were integrated intone software program.

While much has been accomplished, many challenges remain. Further development priorities include the following:

- Integrating economic theories and inputs to enhance the effectiveness of a modeling technique
- Ability to investigate the various policies in isolation and together
- Use of more environmental and social inputs and to generate more and more environmental and social outputs
- Limit the number of roadside interview O-D surveys to prepare the O-D matrix at the major revised stages
- Let the user to select the most suitable mathematical equation for the predictions according to the data on hand at the macro level
- Enhance the ability to outputs at a quick time
- Enhance the user-friendliness of the model
- Develop an interface for accessing the model over the internet, to support coordination of the model application across national, regional and local levels authorities and to provide public access to participate in scenario development and evaluation
- Develop more robust methods for calibrating and validating the system

Finally, this thesis can be regarded as the major step towards of making an integrated transport and land use models in Sri Lanka.

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ANNEXES

Annex 02: Final Counting Locations – District Level

Annex 06: The Survey Form Designed for the Household Surveys

Annex 07: Travel Patterns of Household Types in Each GN Division

Annex 08: The Survey Form Designed for the Week-day Associated Trip

Annex 09: Travel Patterns of Week-day Associated Trip in Each GN Division

Annex 10: The Survey Form Designed for the Household Surveys on Weekends

Annex 11: Travel Patterns of Household Types in Each GN Division on Weekend

Annex 12: The Survey Form Designed for the Railway Travel Surveys

Annex 13: Travel Patterns of Rail Passengers in Each GN Division