EVALUATION OF THE CRITERIA FOR DETERMINING PARKING REQUIREMENTS IN DEVELOPMENT PROJECTS IN URBAN AREAS

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Degree of Master of Science

Department of Civil Engineering

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Thesis submitted in partial fulfillment of the requirements for the degree Master of Science

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DECLARATION

I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

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ABSTRACT

Urban commercial development is an integral part of the urban land use that affects the trip generation pattern in the city. Lack of adequate parking facilities will impact the road network as it will lead to on-street parking. Moreover, the provision of parking within the premises increases in the cost of the development. Therefore, regulations need to ensure that adequate number of parking is required based on the type of development. The parking requirement for office developments in the city of Colombo is based on the gross floor area of the building. But it may not represent the real parking requirement of the building. Therefore, the existing parking regulations for these types of development need to be revised in order to get the optimal parking requirement.

This research is focused on evaluating criteria for determining parking requirements in office development projects of urban areas. The scope of this study is defined as urban office development projects located within the Colombo Municipal Council boundary. To achieve the research aim, it evaluates the adequacy of parking provisions based on the vehicle trip generation patterns for urban office developments. In and Out, surveys were conducted to assess the adequacy of parking provisions. Literature analysis and opinion surveys were used to identify novel criteria for parking demand as well as trip generation. To rank the criteria AHP technique was used. Floor area, Employees, Service population and Parking capacity were ultimately selected as the novel criteria which can affect parking demand and trip generation for office developments.

Regression models were developed to estimate parking demand and daily vehicle trip generation. It was observed that floor area and employees have a significant influence on parking demand and employees, service population and parking capacity have a significant influence on trip generation.

More importantly, based on the study results, five recommendations were developed as due to obsolete and less effectiveness a new method is needed to estimate parking demand with a wide range of criteria, new criteria can be used to determine parking requirements and trip generation for urban office developments, developed models can be used to estimate parking requirement and daily trip generation.

Keywords: Parking requirement, Trip generation, Office developments

DEDICATION

I dedicate this dissertation to Dr. H.R.Pasindu, my supervisor who encourage me to complete this study successfully, Prof. J.M.S.J.Bandara, my co-supervisor who guided me to complete this study and my loving parents who guided and supported me throughout.

M.R.M.Priyadarshanie

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M.R.M.Priyadarshanie

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LIST OF ABBREVIATIONS

Abbreviation	Description
UDA	Urban Development Authority
AHP	Analytical Hierarchical Process
OD	Origin Destination
ITE	Institute of Transportation Engineers
CMC	Colombo Municipal Council
SPSS	Statistical Package for the Social Sciences
MAE	Mean Absolute Error
MAPE	Mean Absolute Percentage Error
AAGR	Average Annual Growth Rate
VOR	Vehicle Ownership Rate
DSD	Divisional Secretariat Divisions
GDP	Gross Domestic Product
USD	US Dollars
MCDM	Multi Criteria Decision Making
DW	Durbin Watson
CCDP	City of Colombo Development Plan
UNDP	United Nation Development Programme
GND	Grama Niladari Division
MC	Municipal Council
PS	Pradeshiya Saba
MLR	Multiple Linear Regression
CI	Consistency Ratio
CI	Consistency Index
RI	Random Index

1 INTRODUCTION

1.1 Background

Parking is an important part of urban transportation and land-use systems and an important asset to any development. (Litman, 2016) Therefore, there is a need to review it considering the city's transportation and land-use system.

The development of commercial activities especially in urban areas has directly affected the increase in trip generation patterns in cities. In the present world, 54% of the population is considered as urban population and it is estimated that within the next 30 years the urban population will be increased by 2.5 billion (United Nations, 2014). Each person starts and ends their trips as pedestrians excluding exceptional trips. In terms of trips using private automobiles, the pedestrian portion of the trip starts or ends at a parking space (Regidor J. , 2006). Therefore, increment in the trip generation has led to a considerable increase in demand for parking, which must be provided within the development**.** Therefore, concerning the demand, more parking spaces should be allocated. But it has been recognized that the existing parking capacity of on and off-street parking does not appear to meet the demand. Lack of adequate parking facilities has a direct influence on the road network. It has led to on-street parking as well as additional vehicular circulation to and from public car parking areas (McCahill, Garrick, & Atkinson-Palombo, 2014). Moreover, the provision of parking within the premises increases the cost to the developer which can escalate the property prices (Kadiyali 2007; Shoup, 1999).

L.R. Kadiyali says one of the problems created by roadside parking is traffic congestion due to obstructions to the flow. In addition to that, he further explains the ill- effects of parking as congestion, accidents, and effects on the environment. Parking utilization analysis done by the city of Annapolis 2017, mentioned the lack of adequate parking resulted in driver frustration, traffic congestion, and illegal parking actions affecting public safety (Parking Utilization Analysis, 2017). Traditionally, parking requirement for development is calculated based on the parking code stipulated in the city parking ordinance and calculation is formulated by considering the gross floor area and size of development (Kuah, 1991)

To forecast the traffic volume several methods are used as a gravity model (L.R.Kadiyali, 2007), Centrality analysis (Jayasinghe, Sano, & Nishiuchi, 2015), connectivity analysis. The mentioned methods calculate the general traffic behavior in a road network based on spatial distribution and linkages. In addition to those ITE trip generation manual is used to estimate trip rates for different types of uses. ITE trip generation can be used to estimates vehicle and person trips during various time periods for a proposed development.

However, due to lack of local norms to indicate accurate traffic generation factors for different types of developments such as office complexes, business establishments, hotel developments, hospitals, recreational areas, etc., it is hard to estimate accurate future traffic figures that will generate due to the proposed new developments (Weerasekera, 2011)

The book, Parking Management Strategies, Evaluation and Planning mentioned that conventional parking standards are based on the parking demand surveys. But these conventional parking standards are extortionate where parking is shared or priced. Therefore, regulations need to ensure adequate number of parking are stipulated based on the type of facility (Litman, 2016).

In Sri Lankan context, Urban Development Authority is the responsible institution that regulates and enforces parking requirements and the parking allocation depends on the type and size of the development.

This study is focused on evaluating criteria for determining parking requirements in development projects of urban areas specifically in office development projects. Therefore, it examines the adequacy of parking provisions, existing parking estimation methods, methods to form parking regulations in the local context as well in the international context. Further, it investigates the effectiveness of existing parking regulations and calculation methods in Sri Lanka. Accordingly, this study develops a methodology and evaluates the criteria for determining parking requirements in development projects of urban areas.

1.2 Research Gap and Problem Statement

In Sri Lanka, UDA is the responsible intuition that regulates and enforces parking requirements. Even though UDA has enforced a set of regulations, the problem is, there is no defined classification especially in the “parking requirements,” which is mentioned in the development plan prepared by the urban development authority. Category of “Office” has been categorized under the commercial type as in the UDA regulations. There are no sub-classifications or different parameters to evaluate parking requirements in an office building. “Floor area” is the only parameter that UDA considered. But when reviewing the international context, there are several sub-classifications as well as there are different parameters to calculate parking requirements except the floor area. Therefore, it helps to evaluate more effective parking requirements as well as helps to estimate accurate future traffic figures.

Due to the lack of a classification of different types of developments such as office complexes, business establishments, etc., it is hard to estimate accurate future traffic figures that will generate due to the proposed new developments. Therefore, to get accurate figures there is a need to introduce novel parameters along with the new models considering the type of usage. This study tries to identify novel parameters which have significant influence on estimating parking requirement by using the literature analysis and the expert opinion survey after reviewing the different office buildings which are located within the city of Colombo.

1.3 Objectives of the Study

1. Evaluate the adequacy of parking provisions based on the trip generation patterns for urban office developments.
2. To identify new parking estimation criteria based on literature analysis and opinion survey.
3. Develop the methodology to estimate parking requirements for urban office developments

1.4 Scope of the Study

This research is focused on evaluating criteria for determining parking requirements in urban development projects and is specifically focused on urban office development projects. Throughout this research, it has identified different modeling approaches that can be used to estimate parking requirements and future vehicle trip generation for an office building. Moreover, it identified the adequacy of existing parking guidelines. To develop the modeling process this research used statistical modeling, regression analysis to examine the relationship between identified variables. To identify the variables/ parameters expertise opinion surveys and literature analyses were carried out. 30 samples of expert opinion data were collected from town planners, architects, engineers, draftsmen, lecturers, transport engineers and transport analysts. To verify the variables/ parameters which were collected from expert opinion survey and literature survey, the Analytical Hierarchical Process (AHP) technique was used.

In and Out, surveys were carried out in 70 office buildings which were in Colombo Municipal Council (CMC) area boundary. Using In and Out surveys and questionnaire surveys following data were collected.

1. Number of In and Out vehicles
2. Parking occupancy
3. Number of employers
4. Number of service population (visitors)
5. Office floor area
6. Number of available parking slots
7. Number of staff vehicles/customer vehicles/office vehicles
8. Mode of the vehicle and Purpose of the trip

To conduct surveys nearly 150 office buildings were identified using land-use maps developed by the Urban Development Authority for the Colombo Municipal council area using Geographic Information System (GIS). Subsequently, considering the floor area, the buildings were classified into three categories using GIS: Geometric Interval Analysis. Ultimately, 70 office buildings out of 150 were selected to conduct surveys. So, each classified level is sufficiently covered in data collection for the study.

Based on the In and Out surveys and questionnaire surveys the first four models were developed based on the ownership of the building and due to some identified limitations, these four models were rejected. Then two regression models were developed to estimate daily vehicle trip generation and parking demand for office developments. To validate the developed models another data set was collected from Sri Jayawardhanapura Kotte Municipal Council area boundary. 10 office developments were selected for the validation representing both government and private.

Throughout this research study, several issues have been noted.

1. Most of the office buildings are allocated parking only for in-house employees and not for visitors or beneficiaries.
2. Most offices encourage the roadside parking.
3. In some developments, parking spaces are under-occupied while in other developments are over occupied due to lack of proper parking management.

1.5 Chapter Breakdown

1.5.1 Chapter 1

The first chapter concludes the background of the research study, Research gap and problem statement, Research objectives and scope of the study. Scope of the study includes general purpose, aspects, facts and theories, subject matters, population or sample, area of the study and the limitations.

1.5.2 Chapter 2

The second chapter explains the literature review. Under that, it describes the theoretical basis of formulation of parking requirement/parking demand, trip generation, existing parking guidelines, parking estimation methods, parking estimation criteria, trip generation estimation methods, office classification methods, factors affecting parking demand and trip generation rates and existing parking standards of urban office developments

1.5.3 Chapter 3

The research methodology is described in chapter 3. Data collection methods, data analysis methods, sample selection and analytical approaches are discussed.

1.5.4 Chapter 4

Chapter 4 describes the analysis and results of the study. Under that, it has identified the essential factors which were affected for the trip generation and parking demand. Ultimately it has developed two regression models to estimate daily vehicle trip generation and parking demand for an office building. Then it includes the model validation.

1.5.5 Chapter 5

Chapter 5 concludes the overall research summary, findings and, recommendations.

2 LITERATURE REVIEW

2.1 Introduction

The literature review focuses on the theoretical basis of formulation of parking requirement/parking demand, trip generation, existing parking guidelines, parking estimation methods, parking estimation criteria, trip generation estimation methods, office classification methods, factors affecting parking demand and trip generation rates and existing parking standards of urban office developments.

2.2 Vehicle population in Sri Lanka

Considering the total vehicle population in Sri Lanka, it has been identified that the rapid increment of total vehicles. From 2012 to 2019 June, there was a considerable increase can be identified. There is a rapid increase in motorcycles than motor cars and motor tricycles. Figure 2.1 illustrates the total vehicle population.

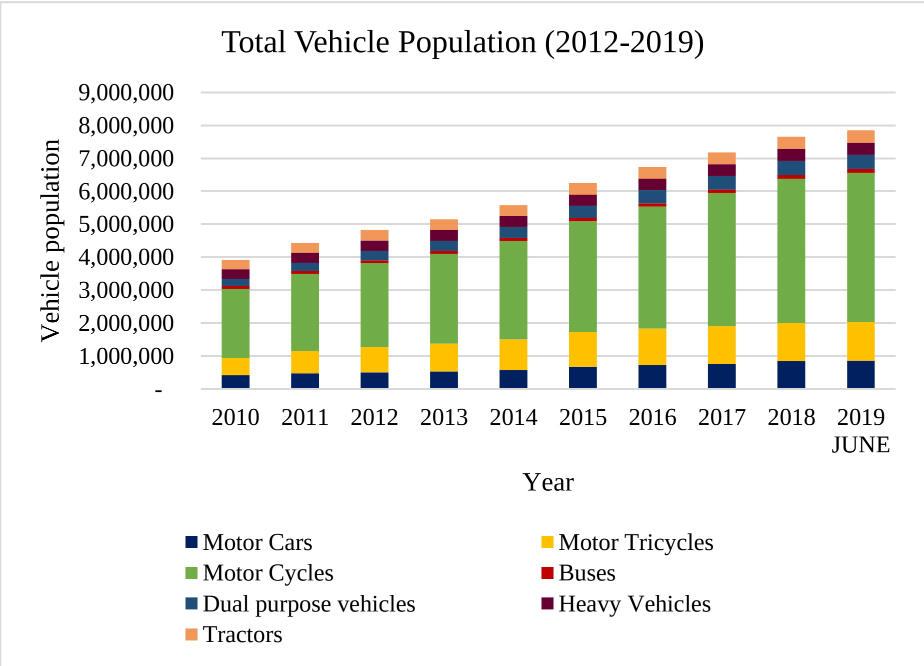

Figure 2.1: Total Vehicle Population (2012-2019)

Source: Department of Motor Traffic

When it comes to the western province, there is a rapid increase can be seen in vehicle population from 2008 to 2017 March. Figure 2.2 represents a detailed illustration. According to the data, the average annual growth rate of the vehicle population of the western province is 7.2%. In 2012 population data, the total population of the western province was 5,821,710 and the average annual growth rate was 0.72% and the AAGR of Colombo district was 0.23%. Comparing the AAGR of population and the total vehicle population in the western province, the vehicle population is significantly higher than the annual population growth rate. By comparing other provinces, the western province has a higher demand for private vehicles. As same as in Colombo district the new vehicle registrations of 2018 represent 72,367.

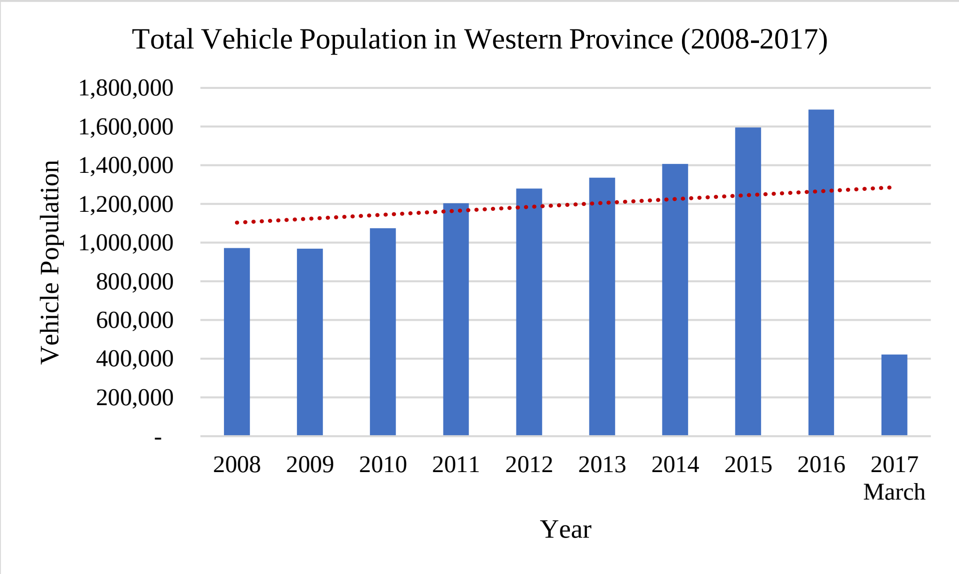

Figure 2.2:Vehicle population in Western Province

Source: Office of the provincial commissioner of Motor Traffic (WP)

2.3 Trip Generation patterns in City of Colombo

Trip generation is a commonly used term in transportation planning. The purpose of the trip generation is to estimate the number of trips generated and attracted by a given spatial unit. Moreover, Trip generation is the most important part of the four-step transport model. There are two types of trip generation models as production models and attraction models (Al-Masaeid & Fayyad, 2018). Production models estimate the number of home-based trips or trip makers reside. Attraction models estimate the non-home-based trips or non-home-based destination. Income, car ownership, family size and composition, land use characteristics, the distance of the zone from the town center, accessibility to the public transport system and its efficiency, employment opportunities can be identified as the factors governing the trip generation and trip generation (L.R.Kadiyali, 2007). Also, the trip generation rate is an important indicator to understand travel behavior and it is also used for measuring future trip generation. (CoMTrans, 2014).

In Sri Lanka, the Western province consists of many government and private institutions, shopping complexes, schools, business-oriented developments, more residences rather than the other eight provinces. According to the Roadside OD interview survey which was conducted in 2013 for the CoMTrans study has been identified the trip purposes of the attracted trips. It has shown in Figure 2.3. It has identified the main three purposes, To home, To work and Private matters. Share of To school, shopping and business trip purposes were very low. The literature mentioned that Colombo had become the most trip attracted city mainly-work trips (Sandaruwan, Karunarathne, Edirisinghe, & Wickramasinghe, 2019). Similarly, in CMC area the peak period is recorded at 7.00 am due to the school and work trips.

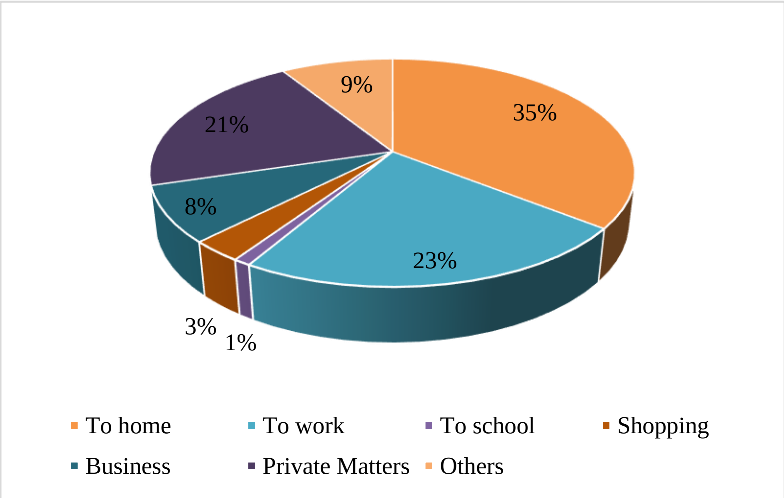

Figure 2.3: Trip Purpose

Source: CoMTrans study 2014

The following figures 2.4 and 2.5 illustrate Home to work trip attraction and Home to work trip productions. According to the CoMTrans estimations within the CMC boundary, there will be a rapid increase in trip attractions by 2025 and 2035.

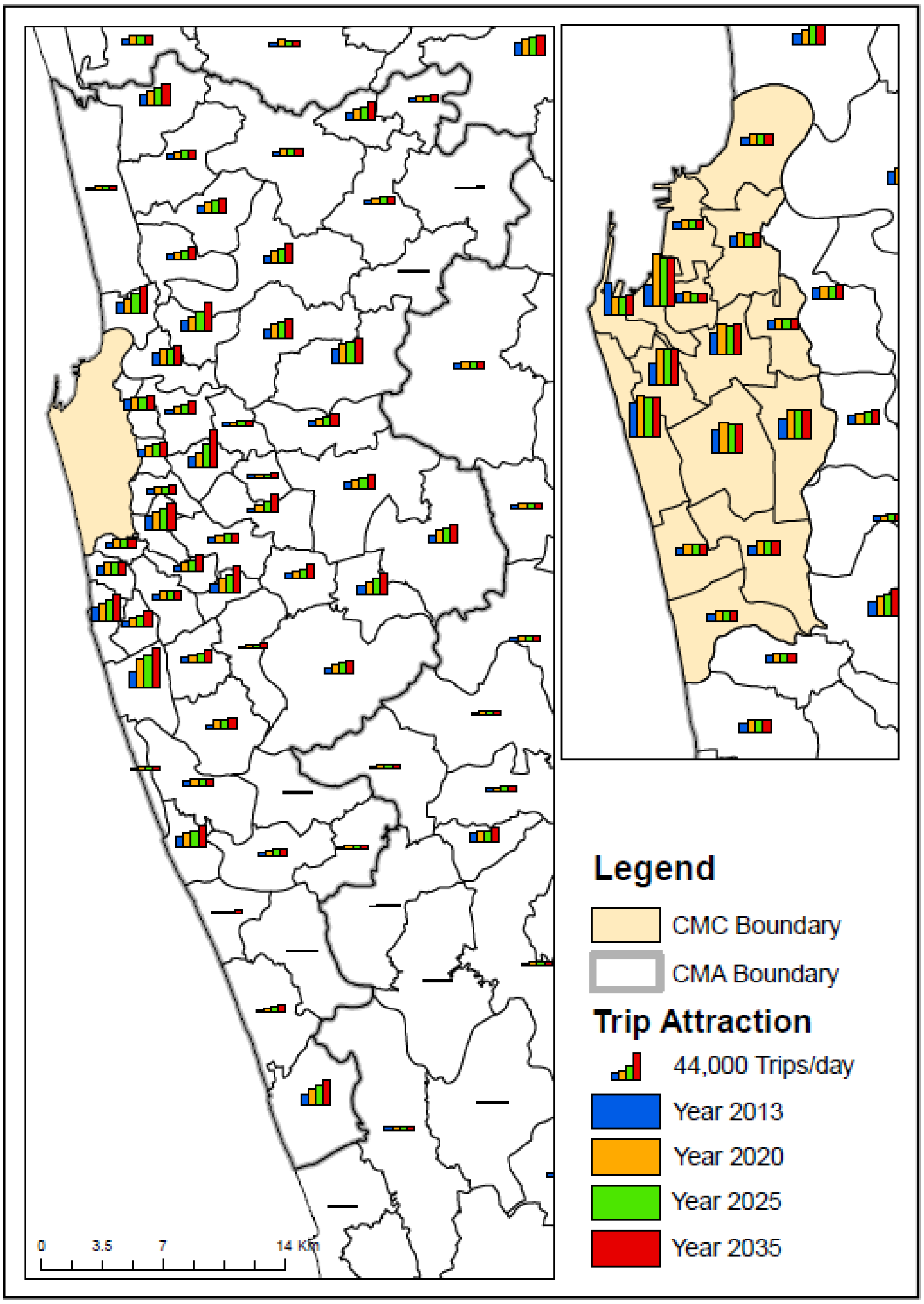

Figure 2.4: Home to Work Trip Attraction

Source: CoMTrans, 2014

Even though there is a rapid increase in trip attraction, the trip productions will be declining by 2025, 2035. The trip production rate of the CMA area will be increased.

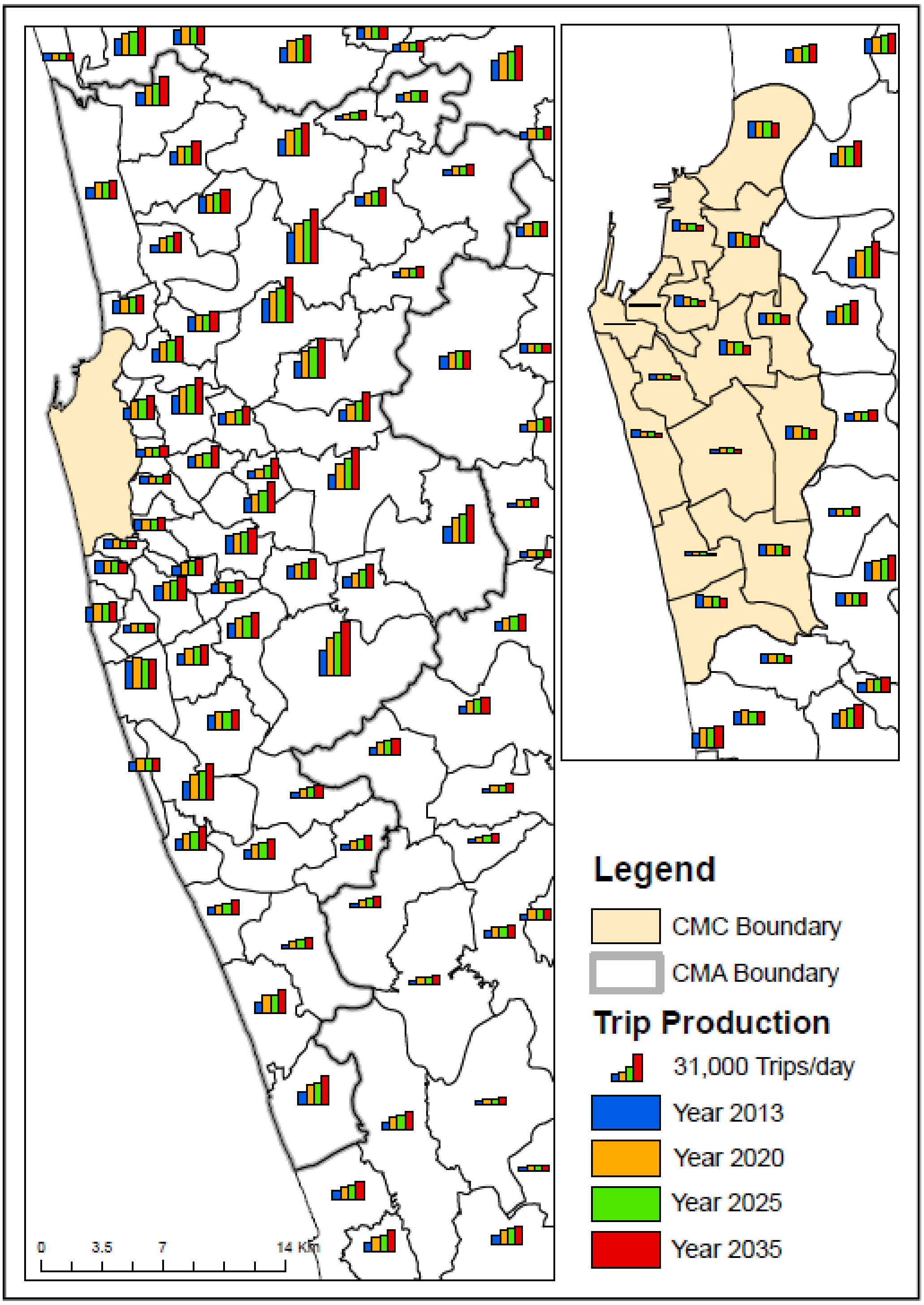

Figure 2.5: Home to Work Trip Production

Source: CoMTrans, 2014

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2.3.1 Existing Trip generation estimation methods in Sri Lanka

In Sri Lanka, to estimate trip generation and attraction for a place, different methods are used. One of the methods is to conduct a survey and identify the trip patterns (OD surveys, In and Out surveys, classified vehicle count surveys, etc.) In addition to that Sri Lanka uses ITE trip generation manual, CoMTrans study as commonly used methods.

For CoMTrans study, trip generation surveys were conducted in 2013 in 10 government office buildings and 10 private office buildings to obtain trip generation rates per unit area, per employee. These trip rates are using for the travel demand forecast, especially for non- home-based trips. To obtain data under the trip generation survey, 5 different surveys were conducted as facility inventory survey, Interview Survey with Business Establishment, Classified Vehicle Count Survey, Person Count Survey and Interview Survey with Facility Users. Based on the analysis, Trip Rates by Number of Employees were estimated and Government and private office, trip rates were 2.43, 3.23 per day, respectively. Similarly, number of trips by gross floor was estimated and government and private office, trip rates were 0.162, 0.155 per day, respectively. The developed method is shown in tables 2.1 and 2.2.

Table 2.1: Average trip rates by registered employees

Facility type	Number of trips by employees (All purpose)			Number of employees	Average trip rate
	Inbound	Outbound	Total		
	A	B	C (A+B)	D	E (C/D)
Government office building	14,918	12,062	26,980	11,121	2.43
Private office building	12,619	10,240	22,859	7,084	3.23

Table 2.2: Average trip rates by gross flow area

Facility type	Number of trips by employees (All purpose)			Gross floor area (m^2)	Average trip rate
	Inbound	Outbound	Total		
	A	B	C (A+B)	D	E (C/D)
Government office building	14,918	12,062	26,980	166,695	0.162
Private office building	12,619	10,240	22,859	147,290	0.155

Source: Urban Transport System Development Project for Colombo Metropolitan Region and Suburbs, Technical Report 3: Characteristics of Present Transport Demand

Except for the above-mentioned studies, there is no advanced model to estimate trip generation for new development. Weeraseka K.S. has mentioned that trip generation was forecasted on available information at the time, for a proposed building complex in Colombo taking it as a study sample (Weerasekera, 2011).

Even ITE trip generation manual is using in Sri Lanka, it is not specifically developed for Sri Lanka, it was developed for the whole world to fit any context. So, the results would be different while applying to the local context. Due to a lack of estimation methods, as well as empirical evidence, it is hard to forecast and identify accurate future traffic figures that will generate due to the proposed developments.

In addition to that gravity model, Fratar Method, connectivity analysis, GIS, centrality analysis, regression-based trip generation models are commonly used methods to forecast trip generation.

2.3.2 Different Trip generation estimation methods in International Context

A considerable amount of research studies has been done to identify different trip generation estimation methods through manuals. Among them, the ITE trip generation manual is one of the famous manuals in the world to calculate trip rates for different types of developments.

Except that New Zealand uses an RTA guide to traffic generating developments, ITE trip generation, NZTPD, and United Kingdom TRICS database (Macababbad, Regidor, & Bartolome, 2009). Australia uses an RTA guide to traffic generating developments as a source of trip rates. Philippines are relying on trip generation rates established by ITE or developed yet questionable local rates (Regidor J. , 2006).

Metro Manila attempted to derive office trip generation characteristics using the ITE manual and focused mainly on "call centers" (Regidor J. R., 2007). South Africa published a Trip Generation Rates document to identify trip generation rates for different developments. UAE, the Emirate of Abu Dhabi also published its trip generation manual (Trip generation and parking rates manual Emirate of Abu Dhabi, 2012). Reid made a criticism on the ITE trip generation manual and developed an alternative method to estimate new trip generation based on the travel survey data. (Reid, 1982) Similarly developed countries have established their trip generation rates for various land uses through field surveys.

Furthermore, to estimate trip generation, regression-based trip generation models (Regression model, Tobit model, Poisson model, ordered logit model), Cross-Classification-type models (Category analysis, Multiple classification), experience-based methods, Land Area Trip Rate Analysis, growth factor modeling are used as conventional trip generation estimation methods. (Chang, Jung, Kim, & Kang, 2014; Mousavi, Bunker, & Lee , 2012)

Except for the above-mentioned methods several studies have been found out trip generation methods as alternatives to the standard ITE approach. They are ITE Multi-Use Method based on vehicle trip data, NCHRP 8-51 Method is based on data collected at six sites and tested at three different sites, United States Environmental Protection Agency (EPA) and San Diego Association of Governments (SANDAG) method based on household travel survey data, URBEMIS ("Urban Emissions") method is based on variables such as density, mixed-use, transit, street connectivity, bicycle and pedestrian facilities, and transportation demand, Metropolitan Transportation Commission (MTC) Survey Method based on the MTC 2000 Travel Survey data, San Francisco method is based on data from the San Francisco Citywide Travel Behavior Survey and traffic analyses, New York's City Environmental Quality Review method based on original pedestrian, bicycle, transit, and automobile person-trip data collected at a nearby site. (Schneider, Shafizadeh, & Handy, 2015)

2.3.3 Factors affecting for trip generation and attraction

Literature has been found that several factors are affecting the trip generation and attraction.

Table 2.3: Factors affecting for trip generation and attraction

Affectng Factors	Source	Published Country or Region
Income, car ownership, family size and composition, land use characteristics, the distance of the zone from the town center, accessibility to the public transport system and its efficiency, employment opportunities, floor space in the premises of industries, shops and offices	(Manchanda & Panda, 2007), (L.R.Kadiyali, 2007)	Rourkela and New Delhi
Area of the building, employees, parking spaces, occupied spaces, persons, vehicles, Dwelling units	(ITE Trip Generation Manual, 2010)	Florida
Number of employees, number of owned vehicles, total GFA and occupied GFA	(Al-Sahili, Abu-Eisheh, & Kobari, 2018)	Jordan
Gross floor area	(A.M.Fillone & Tecson, 2003), (Waloejo, Surjono, & Sulistio, 2012)	Manila and Indonesia

Number of employees, parking lots, visitors, floor area, type of building,	(George, Kattor, & Malik, 2013)	Kerala, India
Area of the development, the number of employees, travel cost, travel time, travel distance, the income of employees, employment status, age of the employee, customers	(Patel, Kedia, & Ravindran, 2016)	India
Type of activity, the modal split of the road network, availability and price of parking, available parking facilities, condition of the adjacent road network	(Mohamed & Hokao, 2000)	Canada
Retail trade floor area, Service and office floor area, Number of employment opportunities in service and offices	(Dodeen, 2014)	Jericho City
Weighted average age, gender ratio, and weighted average household size, average household income, employment ratio, average car ownership population, density, and average distance to transit	(Mousavi, Bunker, & Lee , 2012)	Brisbane, Australia
Gross Floor Area, number of employees	(Macababbad, Regidor, & Bartolome, 2009)	Philippines
Building size, amount of space occupied, number of employees, available parking spaces, and other information	(Delaware Valley Regional Planning Commission, 1990)	Philadelphia, Pennsylvania
Number of parking spaces, Number of subway lines, Distance to nearest Station, Distance to nearest bus stop, Floor area, number of employees	(Ko, 2013)	Seoul, South Korea

2.4 Parking

Industrialization made the world led to higher growth rates of urban economy, living standards and income. As a result of that, there is a continuous growth in private vehicle ownership. (Shen, 1997). The increase in living standards of the people automatically affected the increase in private vehicles in any city. Rather than using public transportation, most people prefer to travel by private-owned cars for their daily routines. Every person who is having a private vehicle needs space for parking. When the vehicle population increases the demand for parking space also increase. The term parking can be defined as "leaving a vehicle in a particular place for a period of time" (Cambridge Dictionary, 2020). Parking is a vital part of the urban transport setting since every vehicle should park at every destination (Litman, 2016). Every private vehicle owner needs a parking space while starts and ends their trips as a pedestrian. In terms of private automobiles, the pedestrian portion of the trip starts or ends at a parking space. (R.P.Roess, Prassas, & McShane, 2011). When the vehicle growth rate getting high, parking has become an imperative element. Hence it creates a requirement while planning each infrastructure. (Parmar, Das, & Dave, 2019). So due to this higher demand, when planning and designing of any infrastructure project, there is a condition or requirement to reserve a space for parking. If ignored, it affected traffic congestion, accidents, wastage of time and money. Also due to lack of parking facilities within the development will lead to on-street parking along the major and minor roads in urban areas (Zu, Jin, & Zhao, 2014). So, there is a necessity to develop proper planning, estimation methods or regulations that cater to the actual demand for different types of developments accordingly.

It is necessary to identify parking characteristics or parking terms that are regularly used in parking studies. Further, it needs to have data on the availability of parking spaces, up to what extent are being used, duration of parking, parking demand or parking occupancy etc. in the initial stage of the study (Parmar, Das, & Dave, 2019). In addition to these basics, the parking terms or parking characteristics should be identified. As per the literature mention parking accumulation, parking volume, parking capacity, parking index, parking load, parking turnover, average parking duration, Peak parking saturation, Peak parking ratio, total parking duration are the commonly used parking terms in parking studies. (L.R.Kadiyali, 2007; Parmar, Das, & Dave, 2019; Mathew, 2014). The detailed definitions are mentioned in chapter three.

2.4.1 Parking types

2.4.1.1 On- Street parking

On-street parking means the vehicles are used to park on the sides of the street. There are common types of on-street parking that can be identified.

- Parallel parking

Parallel parking means the vehicle is parked along the length of the road. This is the safest parking method from accidents. As mentioned in the IRC standards car is taken 5x2.5 (m) space (Mathew & Rao, 2007) and UDA mentioned stall width for angled or parallel parking is 2.4 and length is 4.8 (m) (City of Colombo Development Plan (Amendment), 2008). So, it consumes more space and as a result of that, the minimum number of vehicles can be parked at a given location. Least obstructions to the traffic.

- 30^0 parking

Vehicles are parked at 30^0 with respect to the road alignment. Compare with parallel parking more vehicles can be parked. Minimum obstructions to the traffic flow. (Mathew & Rao, 2007)

- 45^0 parking

Vehicles are parked at 45^0 angles. Therefore, more vehicles can be parked due to their angle. Compare with the parallel and 30^0 parking, more vehicles can be parked at the 45^0 parking (Mathew & Rao, 2007)

- 60^0 parking

Vehicles are parked at 60^0 angles to the direction of the road. Rather than other parking types, more vehicles can be accommodated (Mathew & Rao, 2007).

- Right angle parking

Right angle parking means 90^0 parking. In this type, vehicles are parked perpendicular to the direction of the road. It consumes the maximum width of the curb. This affects obstruction to road traffic. However, maximum vehicles can be accommodated at a given curb length. (Mathew & Rao, 2007)

2.4.1.2 Off-Street Parking

Areas that are exclusively allocated for parking with some distance away from the mainstream of traffic. These parking places are operated by public or private institutions.

2.4.2 Existing Parking regulations in Sri Lanka

In Sri Lanka, Urban development authority is the responsible institution that regulates and enforces parking regulations for all over the country. Planning regulations are formulated by UDA for each district boundary/city boundary along the development plans. UDA is responsible for developing development plans for each UDA declared areas. There is a total 243 number of UDA declared local authority areas have been identified by now as 23 MC, 41 UC and 179 PS. In Colombo district there are 5 MC, 5 UC and 3 PS areas have been declared. There is a development plan for each declared area. As examples in Colombo district; City of Colombo Development Plan (CCDP) for Colombo municipal council area, Moratuwa development plan for Moratuwa area, Sri Jayawardhanapura Kotte development Plan for Sri Jayawardhanapura Kotte area, Maharagama development plan for Maharagama area etc. Except for Colombo, there is a number of development plans for all districts. As an example; Kandy development plan, Kurunegala development plan, Galle development plan, Jaffna development plan etc. As per each development plan, the parking requirement is estimated for each type of developments and it is the only way to estimate parking requirements in the Sri Lankan context.

2.4.3 Parking provisions in Colombo Municipal Council Area

Consider the evaluation of the Colombo development plan process, in the early stage of 1985, UDA has prepared the City of Colombo Development Plan with the assistance of UNDP master plan team to address the challenges of rapid urban growth (Colombo Commercial City Development Plan 2019 – 2030, 2019). This plan consisted of zoning, planning and building regulations. This plan was prepared for the CMC area. The main objectives of the plan focused on the ease of traffic congestion, relocate obsolete land uses such as industries and administrative functions, sensibly locate and layout wholesale and retail trade activities and open up waterfronts and create vistas. In addition, the plan also proposed to redevelop identified slums and shanty areas as special project areas (Colombo Commercial City Development Plan 2019 – 2030, 2019). As mentioned in the 1985 development plan, office parking standards were 1 for 200 sqm.

Afterward in 1999 City of Colombo Development Plan was prepared to address all urban issues as inadequate infrastructure facilities, traffic congestion, urban sprawl, pollution, and inappropriate distribution of activities in the city. The plan explained Land Use Zoning and Building Regulations, Building Density Regulations and Development Guide Plans. As well it included Traffic & Transportation, Infrastructure and Environment & Housing strategies. As mentioned in the city of Colombo development plan 1999, the standard parking requirement for office development was 1 for 200 sqm and two axles commercial(lorry/bus) was 1 for 500 sqm. Finally, in 2008 City of Colombo development plan (Amendment) has been prepared by UDA to including amendments of the 1999 Colombo development plan. (Colombo Commercial City Development Plan 2019 – 2030, 2019). This is the current plan in effect for the city of Colombo.

As per the interviews which were held with planners who were working in preparation of 1999 and 2008 amendment, have mentioned the basics of calculating parking requirement. As per the views, rather than using mathematical calculations, expatriates basically considered practical situations, experiences, current scenarios and surveys. In addition to that, most of the experience was gathered by analyzing the building applications. Based on those factors 1999 and 2008 regulations were formulated. During the process of making such regulations, one of the strategies that identified was to develop all the parking within the premises to reduce traffic congestion and on-street parking. (Plnr.Jayasundara, 2019).

Parking Requirements
Annexure II (A) of Schedule III

(1) Type of Usage	(2) Type of Vehicles		
	Standard	**Two Axle Commercial (Lorry/Bus)**	**Multi Axle Commercial (Truck Semi)**
1. Residential			
i. Flats, dwelling units and terrace houses less than 50 sq.m. in gross floor area	1 for 2 units	-	-
ii. Flats, Dwelling units with Gross Floor Area more than 50sq. m.	1 for 1 unit	-	-
2. Commercial			
i. Retail Shops/Grocery	1 for 50 sq.m.	-	-
ii. Departmental Shops, Shopping Complexes	1 for 50 sq.m.	1 for 500 sq. m.	-
iii. Banks with Customer Services	1 for 50 sq. m	-	-
iv. Hardware	1 for 50 sq.m.	1 for 50 sq.m.	-
v. Offices	1 for 150 sq.m.	-	-
vi. Restaurants and Night Clubs	1 for 10 sq.m. or restaurant space (excluding all service areas)	1 for 500 sq.m.	-
vii. Star Class Hotels	1 for 100 sq.m. or 1 for 5 rooms and 1 for 1 suite, whichever is more	1 for 500 sq.m.	-
viii. Guest Houses, Recreational Clubs and Lodges	1 for 50 sq.m. or 1 for 3 rooms whichever is more	1 for 500 sq.m	-
ix. Cinemas, Theatres, Auditoriums and similar uses.	1 for 20 seats	1 for 500 sq.m	-
x. Factories and Industrial establishments	1 for 200 sq.m	1 for 200 sq.m	1 for 500 sq.m

Figure 2.6: City of Colombo Development Plan (Amendment) 2008

Source: City of Colombo Development Plan (Amendment), 2008

Furthermore, except for the parking standards, there is a necessity to illustrate parking angle degrees which are mentioned in the CCDP 2008 while studying a parking study. Therefore, table 2.4 mentioned the minimum width of aisles. By namely they are 0^0 parallel, 30^0 angles, 45^0 angles, 60^0 angles, 90^0 angles.

Table 2.4: Minimum Width of aisles

Parking Angle Degrees	**One way Traffic one sided bays (meters)**	**One way Traffic Two sided bays (meters)**	**Two way Traffic (meters)**
00^0 parallel	3.6	3.6	6.0
30^0 angle	3.6	4.2	6.0
45^0 angle	4.2	4.8	6.2
60^0 angle	4.8	4.8	6.4
90^0 angle	6.0	6.0	7.2

Source: City of Colombo Development Plan (Amendment), 2008

2.4.4 Parking regulations/provisions in different cities

Summary of the office parking standards is mentioned in table 2.5 which are currently published by Urban development authority.

Table 2.5: Summary of parking regulations

Location	**Type of Usage**	**Type of Vehicles**
		Standard (S)
Sri Jayawardhenapura Kotte	Government/Semi Government	1 for 200 sqm
Rathnapura	Government/Semi Government	1 for 125 sqm
Trincomalee	Other commercial buildings	1 for 100 sqm
Rambukkana	Government/Semi Government	1 for 200 sqm
Panadura	Shop or other commercial building	1 for 100 sqm
Negombo	Shops and other commercial buildings	1 for 100 sqm
Mawanella	Others	1 for 200 sqm

Maharagama	Government/Semi Government	1 for 200 sqm
Kurunegala	Office or Other Commercial Buildings	1 for 100 sqm
Kandy	Other commercial buildings	1 for 100 sqm
Kalmunai	Office	1 for 50 sqm
Kaluthara	Other +commercial buildings	1 for 100 sqm
Kaduwela	Office	1 for 100 sqm
Homagama	Office	1 for 100 sqm
Hambanthota	Others	1 for 200 sqm
Galle	Other Commercial Institutions and Other Commercial Buildings	1 for 100 sqm
Dehiwala-Mount Lavinia MC	Office	1 for 100 sqm
Batticaloa	Other Commercial Institutions and Other Commercial Buildings	1 for 100 sqm
Balangoda	Government / Semi Government	1 for 125 sqm

2.4.5 Parking estimation methods in international context

As per the Sri Lankan context, different countries use different manuals, ordinances, mathematical calculations and guidelines to estimate parking requirements for office developments. Table 2.6 summarized standard parking requirements in the mentioned countries/cities.

Table 2.6: Parking estimation methods in international context

City or Country	Parking estimation method	Type of Usage	Standard parking requirement	Source
Salt Lake City	Building Services and Code Enforcement	General office	3 spaces per 1000 sqft gross floor area for the main floor plus 1 ¼ spaces per 1000 sqft gross floor area for each additional level, including the basement	(Building Services & Code Enforcement, 2012)
		Offices, Research related	3 spaces per 1000 sqft gross floor area	
Washington	Zoning Ordinance	General offices	3.6/1000 sqft. (3.9/100sq.m) of GFA upto 30000 sqft. (3300 sq.m); thereafter 3/1000 sq.ft.(3.2/100 sq.m) GLA	(Chrest, Smith, Bhuyan, Monahan, & Iqbal, 2001)

Los Angeles	Zoning Ordinance	Philanthropic Institution, Government Office, or similar	1 per 500sq.ft	(Department of Building & Safety)
		Commercial or Business Office	1 per 500 sqft	
St Peter Port		Professional Services	1 space per 40 sqm	(Parking Standards and Traffic Impact Assessment, 2016)
		Other offices	1 space per 50 sqm	
Portland		Office	1 per 400 sq. ft. of floor area	(Engstrom, 1996)
Bangkok	Ministerial Regulation	Office	For more than 300 sqm, number of parking space requires 1:60 m^2	(Jittrapirom, 2010)
Sacramento		Offices	Minimum 1 space per 600 GSF in excess of 20,000 GSF Maximum 1 space per 500 GSF in excess of 20,000 GSF	(DKS Associates, 2006)
		Offices (Central city outside)	Minimum 1 space per 450 GSF Maximum 1 space per 400 GSF	

California		Offices; administrative, corporate	1 space for each 250 sq. ft. of gross floor area	(City of Fountain Valley California)
		Offices; not providing on-premises customer service	1 space for each 400 sq. ft. of gross floor area	
Henrico County, West Broad Village	Local Ordinance	Office	1 space per 300 square feet	(Puckett, 2013)
St. Petersburg	City of St. Petersburg City Code	Office Short term space	2, or 1 per 40,000 sq. ft of gross floor area	(Parking and Loading & City of St. Petersburg City Code)
		Long-Term Spaces	2, or 1 per 10,000 sq. ft of gross floor area	
Austin, Texas	Transportation Criteria Manual	Office	45,000 square feet GLA	(Austingtexas gov, 2018)
Alvin, Texas	Code of ordinance	Offices, general	One space for each four hundred (400) square feet of floor area	(Alvin Tx, 2019)
Houstan, Texas	Code of ordinance	Office	2.5 parking spaces for every 1,000 square feet of GFA or 2.75 parking spaces for every 1,000 square feet of UFA	(City of Houston, 2020)

Missoula, Montana	Code of ordinance	Administrative, Professional or General Office	1 space per 480 sq. ft	(Missoula, 2020)

In addition to these mentioned manuals and ordinances, multiple studies have been carried out to identify parking demand estimations in different countries for different uses. Table 2.7 mentioned different types of parking demand estimation methods.

Table 2.7: Different types of parking demand estimation methods

Location/ area	Model type	Factors considered	Source
Hong Kong, China	Linear regression and unit graph technique	Different types of land use variables in terms of relevant units	(Wong, Tong, Lam, & Fung, 2000)
Sydney, Australia	Nested logit model	Departure time, parking price, In vehicle time, personal income, etc.	(Hensher & King, 2001)
Hong Kong, China	Unit graph technique	Search time, walk time, parking fee, in addition to that different land use variables	(Lau, Poon, Tong, & Wong, 2005)
Kolkata, India	Linear regression	Age, income, distance travelled, time index, search and walk time	(Chakrabarti & Mazumder, 2010)
Jinzhou, China	Principal component	Land use of planning area, vehicle population, population and post number	(Bai, Liu, Zhao, & Song, 2011)

	analysis (quantitative analysis)		
Shanghai, China	Gray correlation analysis	Nature of land use, traveler behavior and parking characteristics, parking generation rate, employment and area of building	(Wu & Fan, 2011)
Tel-Aviv, Israel	Discrete choice	Price per hour, search time, waiting time, walk time, duration	(Toledo & Bekhor, 2012)
Tianjin, China	Linear regression analysis	Parking generation rate, average turnover rate, utilization rate, parking price impact coefficient, LOS, growth coefficient of motor vehicles	(Tiexin, Miaomiao, & Ze, 2012)
Ilorin, Nigeria	Linear regression analysis	Ward population, number of vehicles parked, vehicle ownership	(Aderamo & Salau , 2013)
Dong-gu, Korea	Multiple regression model	Factors of detached housing and its area, neighborhood convenience	(Lee, 2014)
James City Country, New Town	Shared parking methodology	Employee, visitors	(Puckett, 2013)
Amman, Irbid, and Zarqa, Jordan	Regression analysis	Building age, No. of floors and apartments, floor area, income, price of apartment, car ownership	(Ghuzlan, Al-Omari, Bashar , Khasawneh, & Mohammad A, 2016)

Kolkata, India	Multiple regression and AHP	Parking generation rate, average turnover rate, utilization rate, parking price impact coefficient, growth coefficient of motor vehicles, cost factor, choice of car over transit	(Das, Ahmed, & Sen, 2016)
Johor, Malaysia	Correlation and regression analysis	Vehicular volume on expressway, size of facility (area)	(Ramli, Hassan, & Hainin, 2017)
Knoxville, USA	Four-stage modeling approach	Generalized cost, walking distance, volume/capacity	(Lim, Williams, & Abdelqader, 2017)
Yogyakarta City, Indonesia	Linear regression model	Parking volume, street length, land use, type of street	(Ajeng & Gim, 2018)

2.4.6 Factors affecting for parking demand/parking requirement for office developments

As per the literature analysis, to formulate parking regulations "floor area" was selected as the most influencing factor. But when it comes to modeling various factors were considered. As mentioned in table 2.7, floor area, the number of employees, visitors, parking capacity, parking volume, income, car ownership, vehicle population, building age etc. has been identified as the most affecting factors for parking demand or parking requirement (Puckett, 2013).

2.4.7 Problems with conventional parking planning

Parking oversupply and less supply are some of the typical parking planning problems in the current context. Even though parking standards are available, developers are trying to facilitate excess parking spaces. Guidelines provide minimum parking requirements for land use. When generalizing these requirements, some developments need parking than the regulated requirement. For example, service-oriented places. These minimum parking requirements do not cater to real demand. So, there is a problematic situation when formulating and enforcing minimum parking regulations. (Puckett, 2013).

Hence several developments facilitate oversupply of parking, some have lack of parking spaces. The developments which did not get the certificate of conformity (COC) were not relying on the parking standards. Old buildings, buildings that changed their uses can be taken as this category. There is another category which was taking the COC and then change the parking arrangements. These mentioned categories are provided excess or fewer parking spaces (Plnr.Jayasundara, 2019). That affects the on-street parking too. Since traffic is increased without addressing the real parking demand, valuable lands are wasted.

Another issue is restrictions on customer parking. Especially while studying office developments, the parking is allowed only for staff and official purposes. Customer parking is not allowed on the premises.

Construction problems can be taken as an issue. Construction problem means the cost for construction of parking. Regulations should be formulated to address the real demand, if it is not addressing the real demand, the developer had to adapt to the typical parking regulation based on the use of the development. The developer should design all the parking within the premises and it may cost more. Proper planning regulations with proper classification methods may reduce the cost of parking and at the same time it will help to reduce wastage of the space.

Reviewing the mentioned issues, one factor is always behind. That is the regulations. There is a conflict between the regulation requirement and actual demand. Therefore, in addition to the regulated requirements, most of the countries are adapted to develop new methods or models to estimate the actual demand for parking.

2.5 Different office classifications in different countries

Different office classifications are used to formulate regulations or a model. As mentioned in table 2.6 in accordance with the country there were various types of classifications that can be identified.

1. Office
2. General Office
3. Administrative, Professional or General Office
4. Offices; administrative, corporate
5. Offices; not providing on-premises customer service
6. Commercial or Business Office
7. Professional Services
8. Institutional buildings
9. Offices, Research related
10. Government office
11. Private office buildings
12. Single tenant office building
13. Small office building
14. Medical- Dental office building
15. Government office complex

2.6 Summary of Chapter

An increase in vehicle population always deals with the increase in trip generation and at the same time provision of parking facilities. In Sri Lanka, the vehicle growth rate is getting increase in day by day. Therefore, an increase in vehicles may have a significant influence on the trip generation rate in a location. To reduce traffic congestion with the growth of vehicle trips, proper parking systems should be facilitated within the development.

This chapter gives a broad picture of an increase in vehicle population in Sri Lanka, Western province and Colombo district. Formerly, it described the trip generation patterns, existing trip generation methods in Sri Lanka and an international context as well. Finally, with empirical evidence, it identified the factors which are affected for trip generation specifically in office development projects.

Similarly, parking studies have described the types of parking, existing parking regulations in Sri Lanka, parking provisions in Colombo Municipal council area, parking regulations and parking estimation methods in international context, factors affecting parking requirements and finally problems with typical parking planning.

Further, different office classifications in different countries were summarized. Based on the trip generation pattern and parking provisions, the research gap is recognized with literature analysis.

When reviewing empirical evidence of trip generation rates in office developments in international context, the evidence is not adequate. There were many pieces of evidences for residential and shopping uses. So, it seems research studies were less when estimating trip rates and parking demand for office developments.

The entire chapter described the concluded facts and figures through empirical evidences.

3 RESEARCH METHODOLOGY

The main objective of this study was to evaluate new criteria for determining parking requirements and trip generations for office development. To achieve this objective, key element that determines the trip generation and parking demand were identified through a comprehensive literature review and expert opinion survey.

Then to develop a methodology to evaluate the adequacy of parking provisions based on the trip generation patterns for urban office developments, In and Out surveys and questionnaire surveys were conducted. Based on the distribution patterns of dependent and independent variables, two models were developed to estimate vehicle trip generation and parking demand.

Using the analysis results, study evaluates the adequacy of existing guidelines for determining parking requirements in urban office development projects.

The research methodology is described in Figure 3.1.

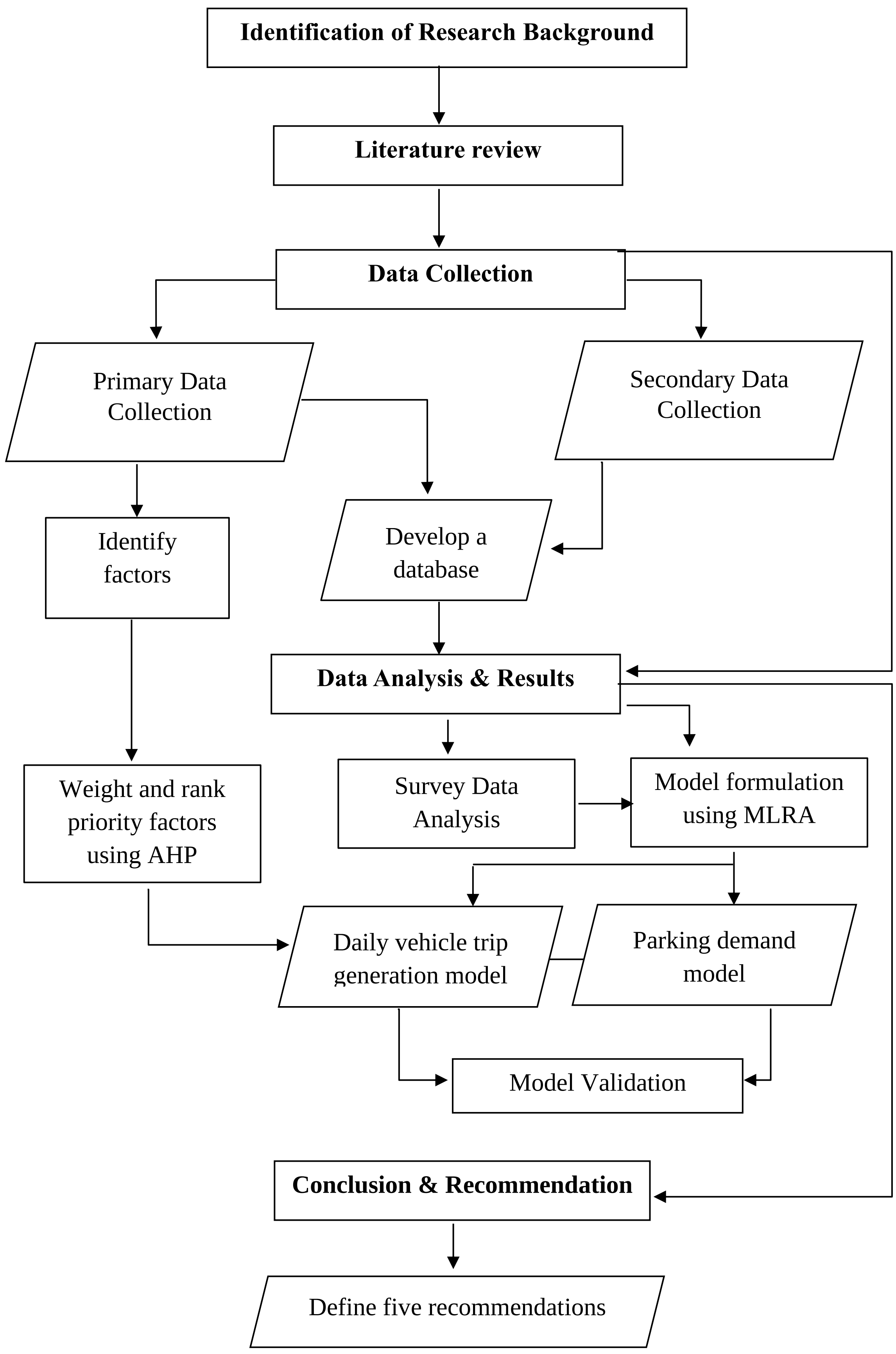

Figure 3.1. Research methodology

3.1 Case study identification

Colombo Municipal Council area (CMC) is selected as the case study of this study. CMC covers the two Divisional Secretariat Divisions (DSD) namely Colombo and Thimbirigasyaya. According to the 2011-12 Census data, the population living within the boundaries of the CMC was 555,031. Out of this 318,048 lived in the Colombo DSD (the Northern part of the city) and 236,983 lived in the Thimbirigasyaya DSD (the Southern part). As mentioned in the city of Colombo development plan 2019-2030, the residential population was estimated as 1.06 Mn in 2017 and 0.82 Mn commuter population.

CMC covers 4,361.6 hectares of land area. It has 4,044.5 hectares of built-up land area and it covers 92% of the total land area. Non- built-up land is 317 ha (8%). Built-up land has been categorized in to six main categories as residential (38.65%), commercial (8.57%), institutional (10.21%), industrial (7.23%), transport (22.51%), public space (6.61%), cultural (2.62%) and under construction (3.62%). Among the total built-up area, 346.58 ha (8.57%) is allocated for all commercial purposes and thereof 29.07 ha (8.3%) is for office developments (Colombo Municipal Council, 2019). Figure 3.4 illustrated the land use pattern of the CMC area in 2017.

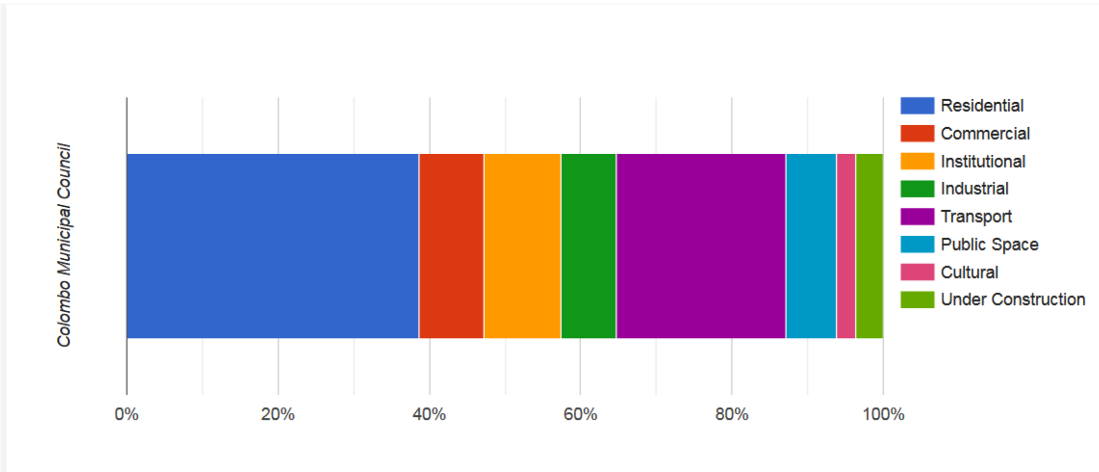

Figure 3.2: Built-up area

Source: SOSLC Project

Colombo MC Land Use Map 2017

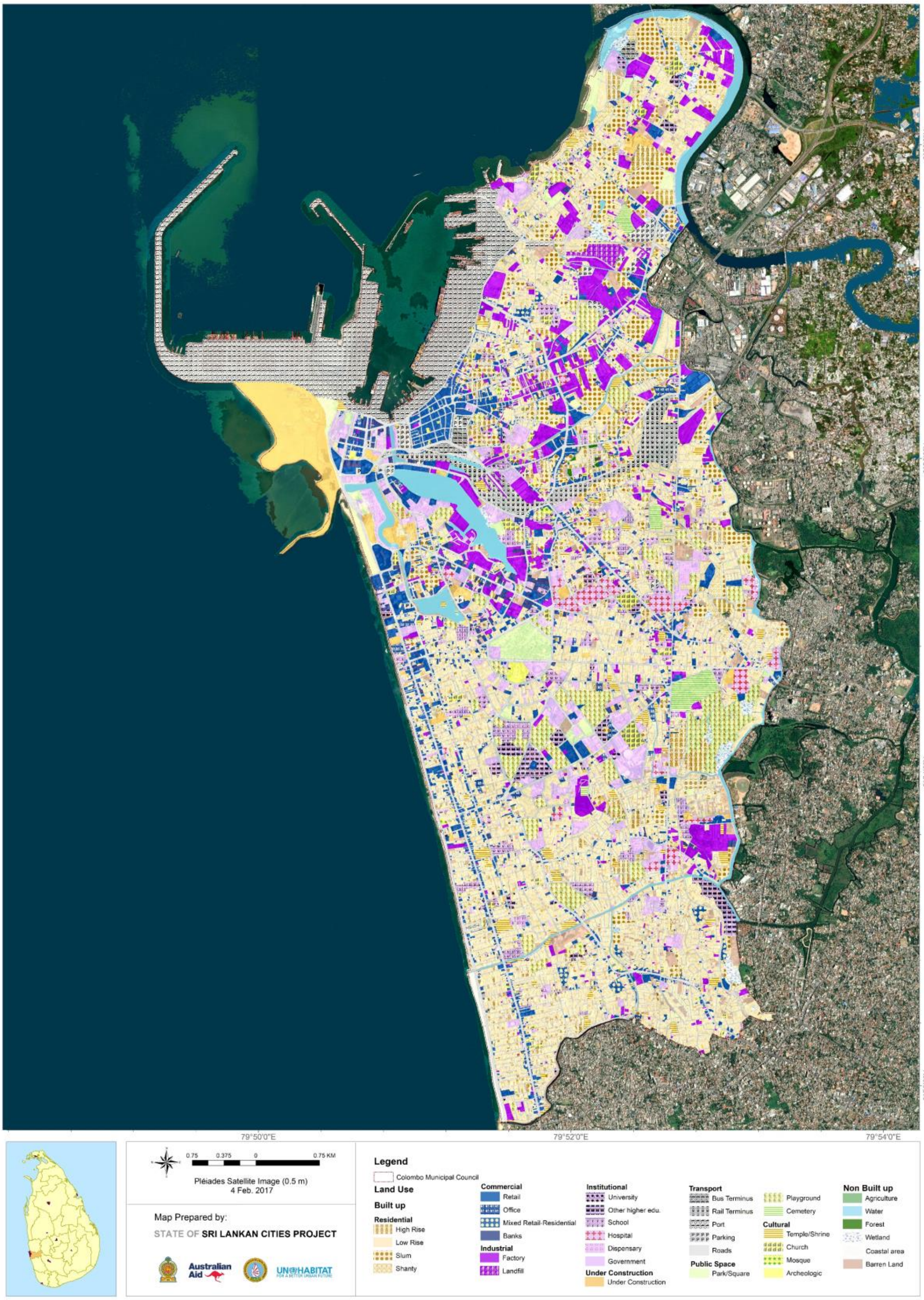

Figure 3.3: Study Area

Source: Colombo Municipal Council, 2019

3.2 Sample Selection

150 office buildings were recognized using maps developed by the Urban Development Authority for the Colombo Municipal council area using the Geographic Information System. Subsequently, Sample selection was carried out by considering the building ownership, condition of the building and floor area of all 150 buildings. Afterward, considering the floor area, the buildings were classified into three categories using GIS: Geometric Interval Analysis (Pappas, 2013). Finally, a sample of 70 buildings representing 47% was selected out of 150 to conduct surveys. So that each classified level is sufficiently covered in data collection for the study.

Table 3.1: Sample Selection

Level	Floor Area	Number of buildings	Sample
1 level	0-1500 sq. m	65	28
2 level	1500-10000 sq. m	75	35
3 level	10000 -15000 sq. m	15	7

28 buildings in level 1, 35 buildings in level 2 and 7 buildings in level 3 were designated. Selected 70 office buildings were represented government, semi-government, and private office buildings 35, 14 and 21 respectively.

3.3 Study Data Collection Methods

3.3.1 In and Out survey

In & Out surveys were conducted on weekdays from 06:00 to 18:00 hours in selected 70 office buildings within the case study area. The data collection included parking volume, available parking slots, gross floor area of the building, parking occupancy rate, parking load, type of vehicle and purpose of the trip. In-Out surveys were conducted coupled with the license plate method survey. First, the vehicles that enter the building were counted and license plate numbers were noted for a time and the same process was continued for the vehicles that leave the building.

3.3.2 Questionnaire survey

A questionnaire survey was carried out in the selected 70 offices during office hours. A questionnaire survey was directly delivered for employees and customers by using an oral question formulation and collected the following data.

1. Number of office employees
2. Number of available parking slots
3. Peak day of a week (trip generation)
4. Availability of the customer parking
5. Availability of inside parking
6. Adequacy of available parking

3.3.3 Person count survey

The surveyors continuously counted the number of persons (visitors) coming into and going out at all the entrance gates of the facilities. The visitors were identified at the security gates and counted the per day visitors.

3.3.4 Opinion survey

To get the ideas and perceptions of expatriates who are working in the transport and planning sector (UDA, CMC, RDA, UOM, ITPSL), the opinion survey was carried out. Accordingly, 30 samples were collected from Town planning professionals, Architects, Engineers, transport specialists, draftsmen, lecturers. The interviewers were represented in different geographical areas in the country. The questionnaire sheet is attached in annexure A.

3.4 Identification of Priority Factors for trip generation and parking demand

Priority factors were identified by the opinion survey as mention in section 3.3.4 and using the literature. Based on the opinion survey five main factors were identified namely floor area, service population, employees, parking capacity, land use characteristics. Factor description is mentioned in table 3.2.

Table 3.2: Factor Description

No.	Criteria	Description
1.	Floor area	The area allocated for the office activities
2.	Employees	Permanent Number of employees who are working in a particular office.
3	Service Population	People who are coming to a particular office to get services
4.	Land Use Pattern	Land use characteristics around the particular office building
5.	Parking Capacity	Number of available parking slots in a particular office building

3.5 Analytical Approaches of the study

3.5.1 Basic principles of Analytic Hierarchy Process (AHP)

Analytic Hierarchy Process (AHP) is a mathematical technique used in multi-criteria decision making (MCDM) to help the decision-maker to select the best choice. AHP provides a convenient approach to analyze the problem (Waris, Panigrahi, Mengal, Soomro, & Mirjat, 2019). Each level consists of a set of parameters with similar characteristics. Similarly, to reduce the complexity of the problem criteria can be divided into subcategories. AHP recommends using a nine-point scale to calculate the relative importance of all elements, comparing them in pairs. There are five steps to be followed to reach the final result. (Waris, Panigrahi, Mengal, Soomro, & Mirjat, 2019)

Step 1: Hierarchy Construction
Step 2: Pairwise Comparison
Step 3: Deriving Relative Weights
Step 4: Checking the Consistency Ratio
Step 5: Synthesizing Results

The numeric comparison scale is mentioned in table 3.3.

Table 3.3: Numeric comparison scale

Numeric Value	Preferred level
1	Equally Preferred
3	Moderately Preferred
5	Strongly Preferred
7	Very Strongly Preferred
9	Extremely Preferred
2,4,6,8	Intermediate values between the two adjacent judgments

The judgmental value for pairs of attributes is recorded in a decision matrix.

$$A=\begin{bmatrix} a_{11} & a_{12} \dots & a_{1n} \\ a_{21} & a_{22} \dots & a_{2n} \\ \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} \dots & a_{nn} \end{bmatrix} \quad (2)$$

"A" represents the judgments or relative importance of alternatives as n x n matrix. n is the number of alternatives. Considering a given condition, matrix A is supplemented with values a_{ij} where a_{ij} denotes the relative judgments between two alternatives. i and j are ith row correspond to the jth column of "A."

$$a_{ii} = 1 \leftrightarrow i = j \quad (3)$$

$$a_{ij} = \frac{1}{aij} \quad (4)$$

aij can also be expressed as,

$$a_{ij} = \frac{w_i}{w_j} \quad (5)$$

where w_i shows the relative weight of the alternative i.

In the third step, relative weights should be estimated for each criterion and sub-criteria. Saaty's eigenvector method is a commonly used method for deriving relative weights. In this method, the corresponding weights of decision elements are determined by comparing the normalized eigenvalue to the principal eigenvalue.

C	A_1	A_2	A_3	…..	A_n
A_1	w_1/w_1	w_1/w_2	w_1/w_3	…..	w_1/w_n
A_2	w_2/w_1	w_2/w_2	w_2/w_3	…..	w_2/w_n
A_3	w_3/w_1	w_3/w_2	w_3/w_3	…..	w_3/w_n
A_n	w_n/w_1	w_n/w_2	w_n/w_3	…..	w_n/w_n

(6)

This is carries out to find the eigenvector "w", where w is,

$$w = (w_1, w_2, w_3, \dots \dots, w_n) \quad (7)$$

The priority vector v is obtained by normalizing the principal Eigenvector w and is called the normalized principal Eigenvector of the pairwise comparison matrix. The overall priority weight of alternatives is computed using equation (8).

$$v_i = \sum_j w_j x_{ij} \quad (8)$$

Where,

V_i = overall priority weight of alternative i,

W_j = weight assigned to criterion j,

X_{ij} = weight of alternative i given criterion j.

Then the consistency ratio is checking. The literature mentioned that an acceptable range of CR should be equal or less than 0.10. (Waris, Panigrahi, Mengal, Soomro, & Mirjat, 2019) The consistency ratio (CR) defined as the ratio of the consistency index (CI) and the random index (RI) is used to use the equation.

$$CR = \frac{CI}{RI} \quad (9)$$

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (10)$$

where *n* is number of alternatives.

The values of the random index (RI) as mentioned in table 3.4.

Table 3.4: RI Values

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

3.5.2 Mean Absolute Error (MAE)

Mean Absolute Error is the measure of errors between paired observations expressing the same phenomenon. In simply it is a difference between estimated and actual value. MAE is calculated by subtracting the estimated value into the actual value. Then it divided by again actual value.

MAE= (Actual value- Estimated value)/ Actual value (11)

3.5.3 Mean Absolute Percentage Error (MAPE)

MAPE results interpret the accuracy level of the forecast as, less than 10% is high accurate forecast, 11% to 20% is a good forecast, 21% to 50% is reasonable to forecast, and 51% or more is an inaccurate forecast. (Chen, Bloomfield, & Fu, 2003)

*MAPE= [(Actual value- Estimated value)/ Actual value]/n*100%* (12)

3.6 Parking terms

The parking terminology used in the study is described as follows.

3.6.1 Parking Accumulation

Parking accumulation is the total number of vehicles parked at a particular interval of time. Normally it is expressed by the accumulation curve. The graph represents the number of bays occupied with respect to time. (Rahman, Kuhu, Shakil, & Quadir, 2011)

3.6.2 Parking Volume

The number of vehicles parked in a particular area over a given time. It is usually measured in vehicles per day. (Mathew & Rao, 2007)

3.6.3 Parking load

The total number of vehicles parked in an area at a specified moment obtained by multiplying the number of vehicles occupying the parking area at each time interval with the time interval. (Mathew & Rao, 2007)

3.6.4 Average Parking Duration

It is the ratio of total vehicle hours to the number of vehicles parked. (Mathew & Rao, 2007)

$$Average\ parking\ duration = \frac{Parking\ load}{Parking\ volume} \quad (13)$$

3.6.5 Parking Turnover

It is the ratio of several vehicles parked during a particular time interval to the number of parking bays available. (Mathew & Rao, 2007). In simple terms, how much is the average time of use of one parking space for a specified period. Higher turnover means better use of parking capacity. It means more vehicles will be serviced in the same capacity. (Naydenov, 2010)

$$Parking\ turnover = \frac{Parking\ volume}{No\ of\ bays\ available} \quad (14)$$

3.6.6 Parking Index

It is defined as the ratio of a number of bays occupied in time duration to the total space available. The parking index is called occupancy or efficiency.

$$Parking\ Index = \frac{Parking\ load}{Parking\ Capacity} * 100 \qquad (15)$$

3.6.7 Parking demand

Parking demand the number of parking that would be used in a particular time and place (Rahman, Kuhu, Shakil, & Quadir, 2011). Parking demand is affected by vehicle ownership, geographic location, parking duration, trip rate, service type, mode split, type of trip and the quality of travel alternatives. (Rahman, Kuhu, Shakil, & Quadir, 2011)

3.6.8 Parking supply

Parking supply is the availability of parking spaces. The availability of parking spaces depends on the large measure of the intensity of development and the cost of the land. (Rahman, Kuhu, Shakil, & Quadir, 2011) The parking supply is governed by the parking regulations and ordinances.

3.7 Summary of Chapter

This study has been developed three objectives. To achieve these objectives different methods have been used. To carry out the study, Colombo Municipal Council area was selected as the case study. Formerly, 150 office buildings were identified using the CMC land use map and among them, 70 buildings were selected. This was included 35 government office buildings, 14 semi-governments and 21 private office buildings.

Throughout this chapter, it was concluded all the data collection methods and techniques which have been used for this research study. The data collection consisted of In and Out surveys, questionnaire surveys, person count surveys and opinion surveys. To analyze the opinion survey data, the AHP technique was used. Except for that, SPSS software and GIS software have been used.

Further to analyze survey data, a different type of parking terms was used as parking accumulation, parking load, parking turnover, parking index, parking volume, average parking duration, parking demand and parking supply. To formulate the model, multiple linear regression analysis was applied in SPSS software. Lastly, to validate developed models Mean absolute error (MAE) and Mean absolute percentage error (MAPE) concepts were used.

4 ANALYSIS AND RESULTS

To evaluate the adequacy of parking provisions and to develop the methodology to estimate parking requirements for urban office developments, two-stage of analysis were conducted. Survey data analysis was stage I, to identify the adequacy of parking provisions and stage II was to develop a methodology to estimate parking demand as well as trip generation models with the SPSS analysis.

4.1 Analysis of opinion survey data

Due to lack of literature, the study has conducted an expert opinion survey to get expert ideas regarding the parking regulations and trip generation patterns. 30 samples of experts participated in this survey. The online google form was distributed among urban planners, architects, engineers, lecturers, draftsmen and consultants who were working in urban development authority, Road development authority, Department of Town & Country planning, Colombo Municipal Council and few different private offices. Based on the opinion survey, the study has identified five main factors which were affected for parking demand and vehicle trip generation.

Analytical Hierarchical Process (AHP) was used to rank the selected factors for trip generation as well as parking demand. In the first stage, factors were nominated by experts and in the second stage, the ranking was done.

4.1.1 Analysis and results of AHP for parking demand

Based on the expert's opinion, factors namely floor area, employees, service population, parking capacity and land use characteristics were selected. Then, to rank the selected factors, the AHP technique was used. It was done by adapting a standard process.

Step 1: Hierarchy Construction (Hierarchy Structure of Goal, Criteria)

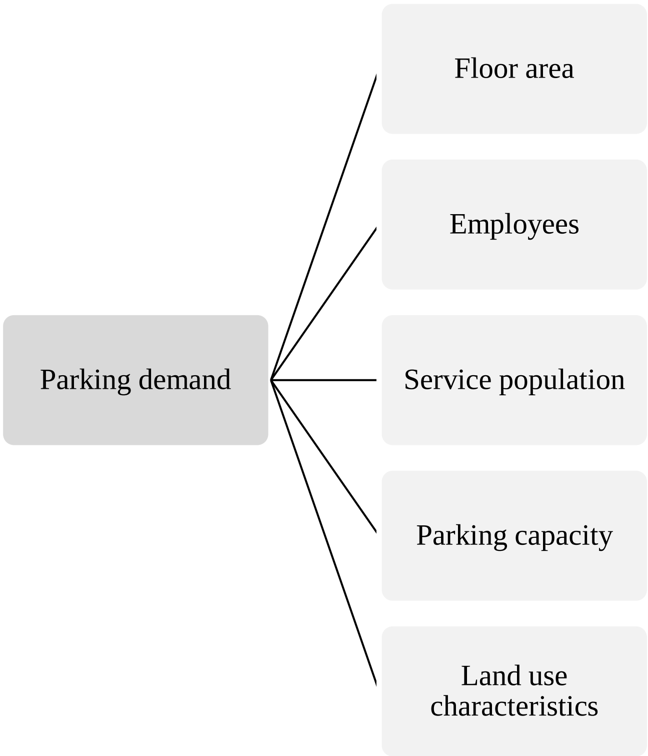

Figure 4.1: Hierarchy Structure of Goal, Criteria and Sub Criteria

Step 2: Pairwise Comparison

During the step of pairwise comparison, the factors in each set of the hierarchy were compared with their corresponding group members. This pairwise comparison was done with the nine-point scale and the detailed description is given in section 3.5.1. This is the choice of preference between two factors on the number scale. Therefore, there is no correct or incorrect answer. In this study, the pairwise comparison of the criterion of the decision hierarchy model was done with 30 expert professionals. An example of pairwise comparison matrix is described in table 4.1.

Table 4.1: Pairwise comparison of factors

Criteria	9	7	5	3	1	3	5	7	9	Criteria
Floor area								7		Employees
Floor area									9	Service Population
Floor area					1					Parking capacity
Floor area			5							Land use characteristics
Employees					1					Service Population
Employees				3						Parking capacity
Employees	9									Land use characteristics
Service population							5			Parking capacity
Service Population		7								Land use characteristics
Parking capacity			5							Land use characteristics

According to the above-mentioned comparison, employees are very strongly preferred compared with the floor area. Service population is extremely preferred than floor area. Floor area and parking capacity are equally preferred to each other while floor area is strongly preferred than land-use characteristics. Employees and service population are equally preferred to each other, and employees are moderately preferred compare with the parking capacity. Employees are extremely preferred than land-use characteristics. Parking capacity is strongly preferred over service population and parking capacity is strongly preferred over the land use characteristics. Individual consistency tests were carried out in this stage.

Step 3: Deriving Relative Weights

As per the third step, this step requires the estimation of relative weights for each of the criteria and sub-criteria of the decision hierarchy. Table 4.2 matrix was developed using the average value of scores.

Table 4.2: Comparison matrix- Parking demand

Criteria	Floor area	Employees	Service Population	Parking Capacity	Land use characteristics
Floor area	1	1/2.13	1/4.2	1.66	1/0.46
Employees	2.13	1	1/3.3	4.73	5.4
Service population	4.2	3.3	1	5.26	6.2
Land use characteristics	1/1.66	1/4.73	1/5.26	1	1/0.33
Parking capacity	0.46	1/5.4	1/6.2	0.33	1
Column Sum	**8.39**	**5.15**	**1.88**	**12.98**	**17.8**

In order to give relative weights to each criterion, the normalization should be done for the above-mentioned (Table 4.2) matrix. Normalization is done by dividing each value by the column sum value. The priority weight of each factor was given by the average of the normalized relative weight. Priority weights of each factor were obtained by the AHP technique and shown in table 4.3. As per the priority weights, service population factor has obtained the highest weight, then employees, floor area, parking capacity and land use characteristics respectively. According to the results, while the service population gets the highest weight, land use characteristics gets the least weight. Hence these eigenvectors (priority weights) are not consistent, before finalizing the results, the consistency test should be carried out.

Step 4: Checking the Consistency Ratio

AHP allows a 10% inconsistency in human judgment. To check the reliability of decision-makers' judgment, the consistency ratio (CR) is used. CR is defined as the ratio of the consistency index (CI) and the random index (RI). The values of the random index are different from the size of the matrix were adopted. Also, a matrix is considered, consistent only if $CR > 0.10$ (Gunasoma, 2018). The consistency ratio of this comparison has obtained 0.069 (6.9%) value and the results were accepted.

Table 4.3: Normalized Matrix with Weights of Criterion (Parking demand)

	Floor area	Employees	Service Population	Parking capacity	Land use characteristics	Total	Priority weights	Priority weights (%)
Floor area	0.119	0.089	0.122	0.128	0.122	0.581	0.116	**11.61**
Employees	0.254	0.194	0.160	0.364	0.303	1.275	0.255	**25.50**
Service population	0.501	0.641	0.532	0.405	0.348	2.427	0.485	**48.53**
Parking capacity	0.072	0.041	0.101	0.077	0.170	0.461	0.092	**9.21**
Land use characteristics	0.055	0.035	0.085	0.025	0.056	0.256	0.051	**5.12**

Consistency ratio: 0.069

4.1.2 Analysis and results of AHP for daily vehicle trip generation

As same as the section 4.1.1, the AHP analysis was done to rank the selected factors which were affected for daily vehicle trip generation. This is also adapted as standard process.

Step 1: Hierarchy Construction (Hierarchy Structure of Goal, Criteria)

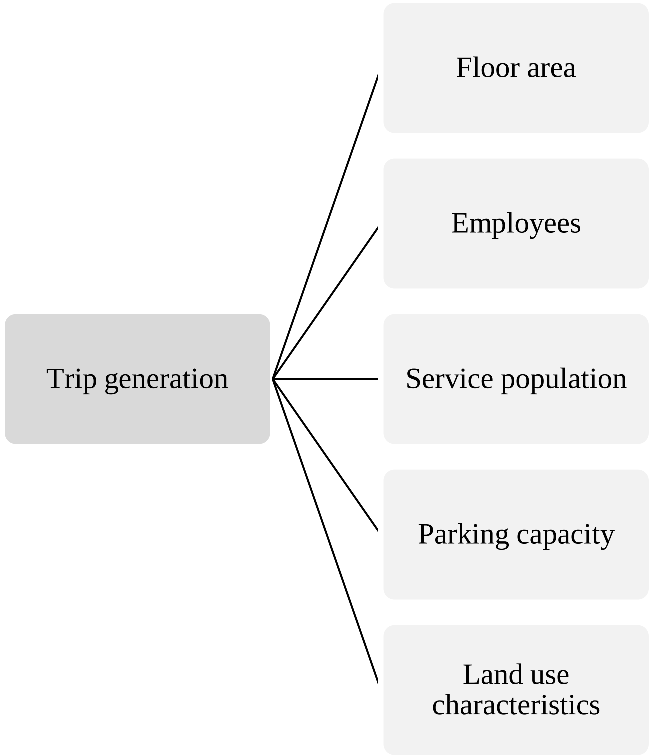

Figure 4.2: Hierarchy Structure of Goal, Criteria and Sub Criteria

Step 2: Pairwise Comparison

Similarly, pairwise comparison was conducted with a nine-point scale. In this study, the pairwise comparison of the criterion of the decision hierarchy model was done with 30 expert professionals. Individual consistency tests were carried out in this stage.

Step 3: Deriving Relative Weights

As per the third step, this step requires the estimation of relative weights for each of the criteria and sub-criteria of decision hierarchy. Table 4.4 matrix was developed using the average value of scores.

Table 4.4: Comparison matrix- Daily Trip generation

Criteria	Floor area	Employees	Service Population	Parking Capacity	Land use characteristics
Floor area	1	1/2.26	1/4.26	1	1/0.4
Employees	2.26	1	2.26	4	3.2
Service population	4.26	1/2.26	1	3.73	4.4
Land use characteristics	1	1/4	1/3.73	1	1/0.33
Parking capacity	0.4	1/3.2	1/4.4	0.33	1
Column Sum	**8.92**	**2.45**	**3.99**	**10.06**	**14.13**

Once the normalization was done, the priority weights were calculated. The priority weight of each factor was given by the average of the normalized relative weight. Table 4.5 illustrates the results. Priority weights of each factor were obtained by the AHP technique and shown in table 4.5. As per the priority weights “employees” factor has obtained the highest weight, then service population, floor area, parking capacity and land use characteristics, respectively. According to the results when the employees got the highest weight, land use characteristics got the least weight. Before finalizing the results, the consistency test should be carried out. Hence these eigenvectors (priority weights) are not consistent.

Step 4: Checking the Consistency Ratio

Hence AHP allows a 10% inconsistency in human judgment, to check the reliability of decision-makers' judgment, the consistency ratio (CR) is used. CR is defined as the ratio of the consistency index (CI) and the random index (RI). The values of the random index are different from the size of the matrix were adopted. Also, a matrix is considered, consistent only if $CR > 0.10$ (Gunasoma, 2018). The consistency ratio of this comparison has obtained 0.097 (9.7%) value and the results were accepted.

Table 4.5: Normalized Matrix with Weights of Criterion (Trip generation)

	Floor area	Employees	Service Population	Parking capacity	Land use characteristics	Total	Priority weights	Priority weights (%)
Floor area	0.112	0.181	0.059	0.099	0.177	0.628	0.126	**12.561**
Employees	0.253	0.409	0.566	0.398	0.226	1.852	0.370	**37.049**
Service population	0.478	0.181	0.251	0.371	0.311	1.591	0.318	**31.823**
Parking capacity	0.112	0.102	0.067	0.099	0.214	0.595	0.119	**11.906**
Land use characteristics	0.045	0.128	0.057	0.033	0.071	0.333	0.067	**6.661**

Consistency ratio: 0.097

4.1.3 Summary of AHP result

When concluded the AHP process, 30 experts' opinions were collected, analyzed, and identified the most influencing factors for parking demand and daily vehicle trip generation for urban office developments. In the very first-stage factors were nominated by experts and in the second stage, these factors were rank according to their preferences. In this stage, individual consistencies were checked in each pairwise comparison. Floor area, employees, service population, parking capacity and land use characteristics were nominated as criteria for parking demand and using the AHP technique criteria were weighted and ranked as service population, employees, floor area, parking capacity and land use characteristics. It obtained a 0.069 CR value and the results were acceptable.

Similarly, floor area, employees, service population, parking capacity and land use characteristics were nominated as criteria for daily trip generation and using AHP technique criteria were weighted and ranked as employees, service population, floor area, parking capacity and land use characteristics. It obtained a 0.097 CR value and the results were acceptable.

4.2 Survey Data Analysis

4.2.1 Distribution of Daily vehicle trip generation

The daily vehicle trip generation is an important indicator to understand the trip generation behavior of office buildings. Figure 4.3 shows the arrival of vehicle trips from 06:00 to 18:00 hours. This comprises the total number of vehicle trips that are attracted to the office (attraction) and the number of trips that are generated from the office (production).

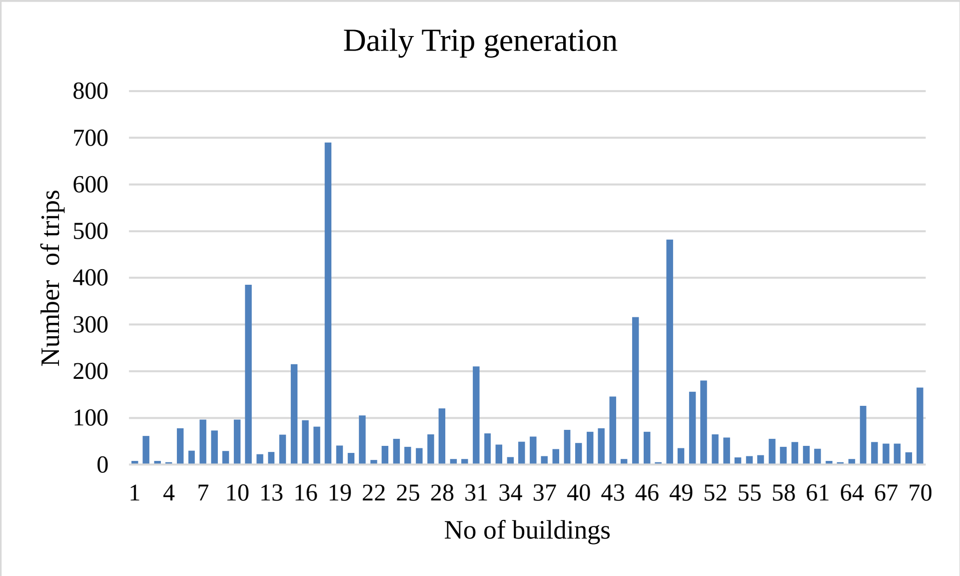

Figure 4.3: Distribution of daily trip generation

4.2.2 Parking Volume

Figure 4.4 shows the number of vehicles parked in the office premises during a specific time period of a day. Parking volume is counted excluding drop off and pick up vehicles.

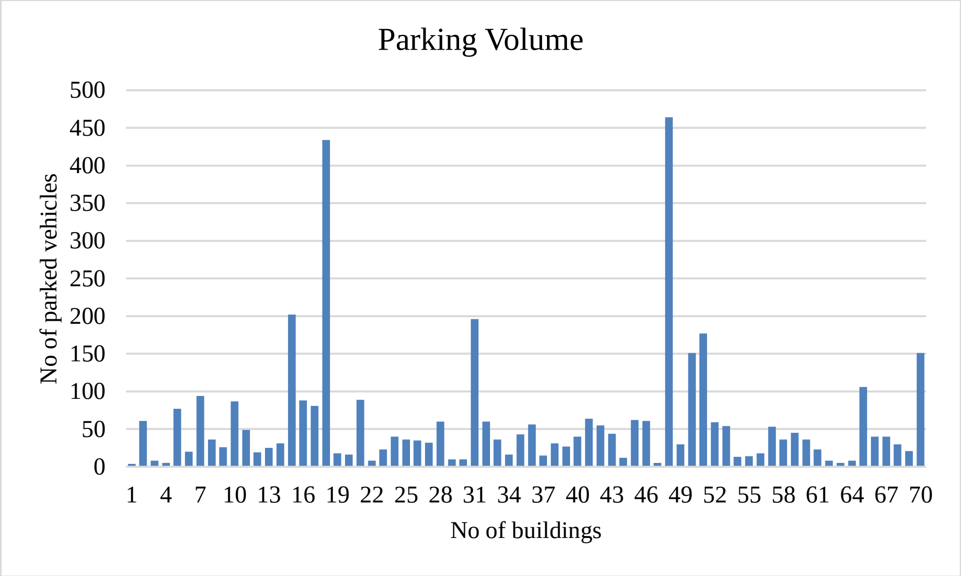

Figure 4.4: Distribution of parking volume

4.2.3 Total Parking Duration

Figure 4.5 shows the total parking duration in vehicle hours. Total parking duration is the total number of vehicles parked in an area at a specified moment (Parking load). It was calculated by using In-out surveys. The results perform that 29% of vehicles are parked for 10-50 hours, 36% of vehicles are parked for 51-100 hours and 14% of vehicles are parked during a 101-150-hour time period for a particular day. It normally predicates a total of 65% of vehicles are used to park during a 10 to 100-hour time for a day.

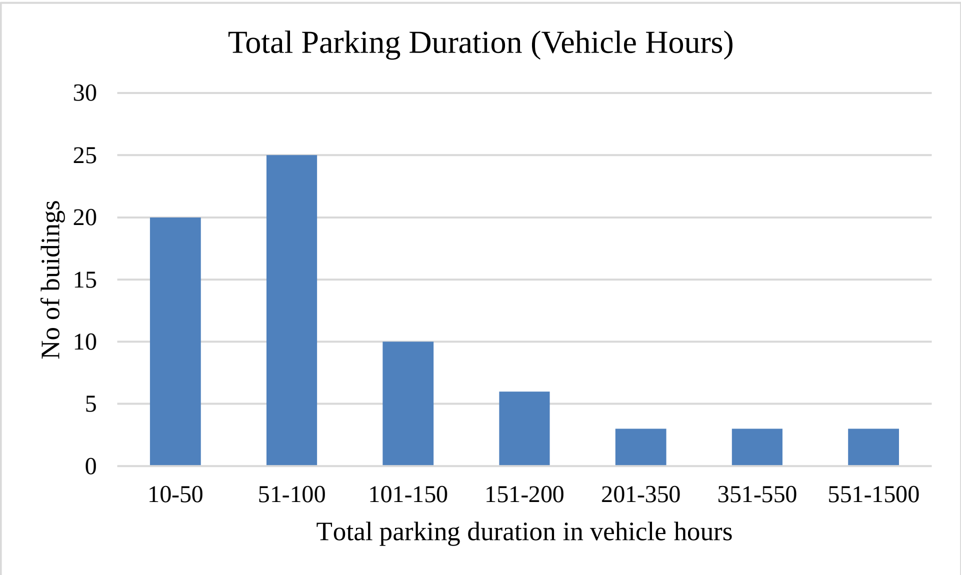

Figure 4.5: Distribution of total parking duration

4.2.4 Average Parking Duration

The average parking duration is the ratio of total vehicle hours to the number of vehicles parked. It is calculated by dividing parking load into parking volume and the results interpret in average 1-3 hours a vehicle used to park for a place.

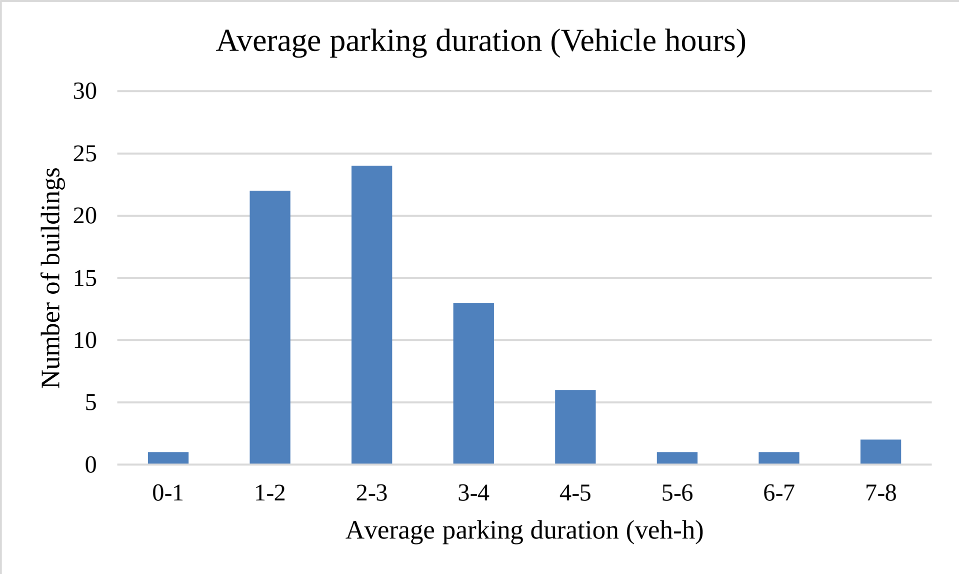

Figure 4.6: Distribution of Average parking duration

4.2.5 Parking Turnover

Parking turnover is a frequency of occupation of a parking slot within the considered time period. The result indicates that, on average a parking slot is being occupied 1-3 (75%) times per day in an office building.

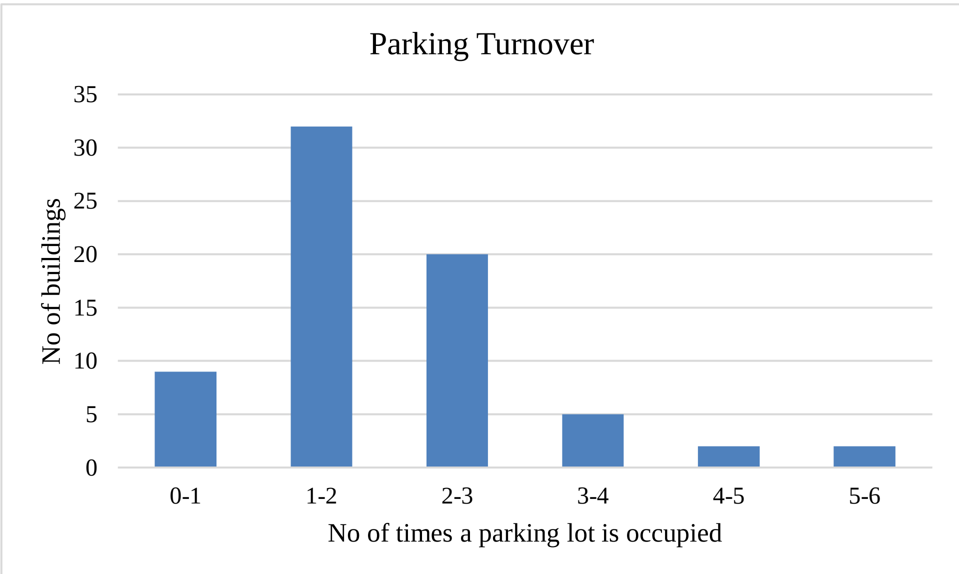

Figure 4.7: Distribution of parking turnover

4.2.6 Parking Index

Parking index is used to identify as the utilization rate of the provided parking slots. Out of the 70 buildings sample, two buildings have reached 100% parking index and one building is beyond their parking capacity. 4% of buildings are included in >80 category, 3% of buildings are included in the range of 70-80, 6% of buildings are included in the range of 60-70, 16% of buildings are included in the range of 50-60, 17% of buildings are included in the range of 40-50, 16% of buildings are included in the range of 30-40, 20% of buildings are included in the range of 10-20 and 1% of buildings are in below 10 range. The utilization of parking below 50% indicates that the buildings have excess parking facilities. In this graph, 71% of the data are below 50%. Only 29% of data belongs to more than 50%. Therefore, it evidently indicates that there is a mismatch in the parking requirement and parking allocation.

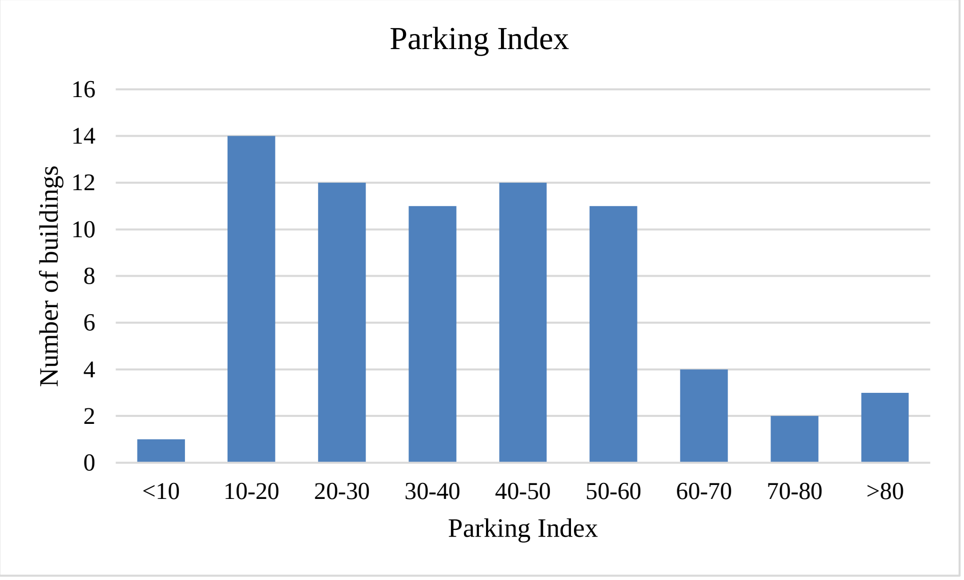

Figure 4.8: Distribution of total parking Index

4.2.7 Distribution of trips by vehicle mode

Figure 4.9 demonstrates the total vehicle composition. 48% of employees and visitors are used Car/Suv as their transport mode. Similarly, 26% of van/pickup, 12% of motorcycles, 9% of three-wheelers, 3% of lorries and 2% of passenger vehicles were identified using In and Out surveys.

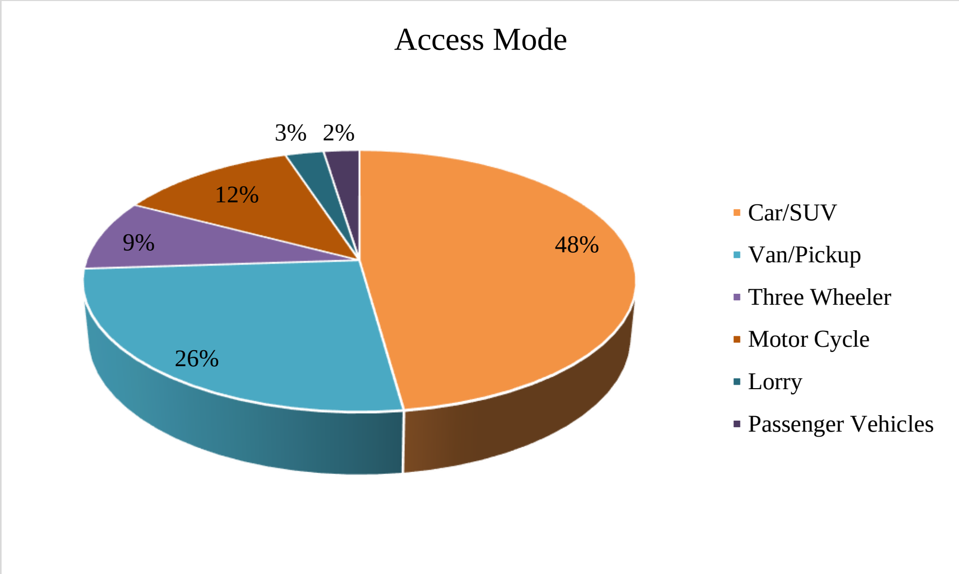

Figure 4.9: Distribution of trips by vehicle mode

4.2.8 Distribution of vehicle trips by trip type

Figure 4.10 illustrates the distribution of vehicle trips in a total of 70 office buildings by trip type. The following trip types were identified using surveys as staff vehicle trips, customer vehicle trips, drop off/pickup vehicle trips, internal office vehicle trips, external office vehicle trips and other vehicle trips. As per the illustration 31% internal office vehicle trips, 23% customer vehicle trips, 17% external office vehicle trips, 15% staff vehicle trips and 2% other vehicle trips were identified. Internal office vehicles mean the vehicles which are owned by the particular office. External office vehicles mean the vehicles which are coming from other offices for official purpose. Customer vehicles show 23% and it is relatively less because some offices have restricted customer parking and at the same time some are not provided direct services for the customers.

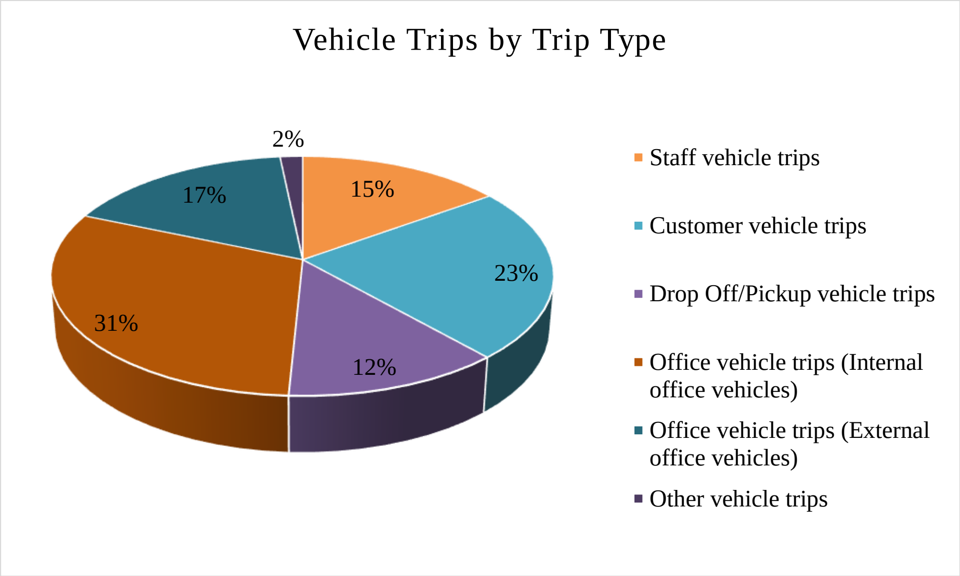

Figure 4.10: Distribution of vehicle trips by trip type

According to the individual analysis of employee trips, it has identified 15% of employees use private vehicles while the rest of 85% use public transport. This survey includes the 35 government offices, 14 semi-government offices and 21 private offices. Only 7% of government servants use private vehicles out of 35 samples. The remaining 93% use public transport, staff services, or drop off/pick up vehicles. As the same 10% of private office servants use private vehicles out of 21 samples and 6% of semi-government servants use private vehicles out of 14 samples. Therefore, figure 4.11 results can be verified, and it can be identified the government servants and semi-government servants use public transport modes rather than using private vehicles.

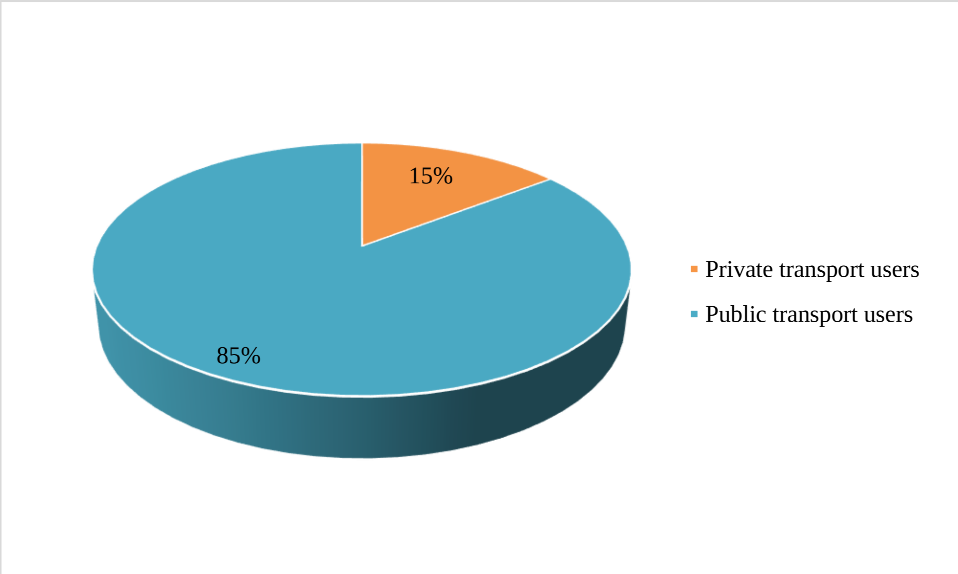

Figure 4.11: Selection of private/public transport facilities of office employees

4.2.9 Distribution of Daily vehicle trip generation vs parking demand

Figure 4.12 demonstrates the distribution of daily vehicle trips and parking volume. It shows that all the attracted trips did not use parking. Because, figure 4.10 shows, 12% of drop off and pickup vehicle trips. So that 12% did not count as the parked vehicles. Another thing is some of the office parking slots are not allowed for customers. So, the situation is, all those trips were counted but it was not counted as parked vehicles.

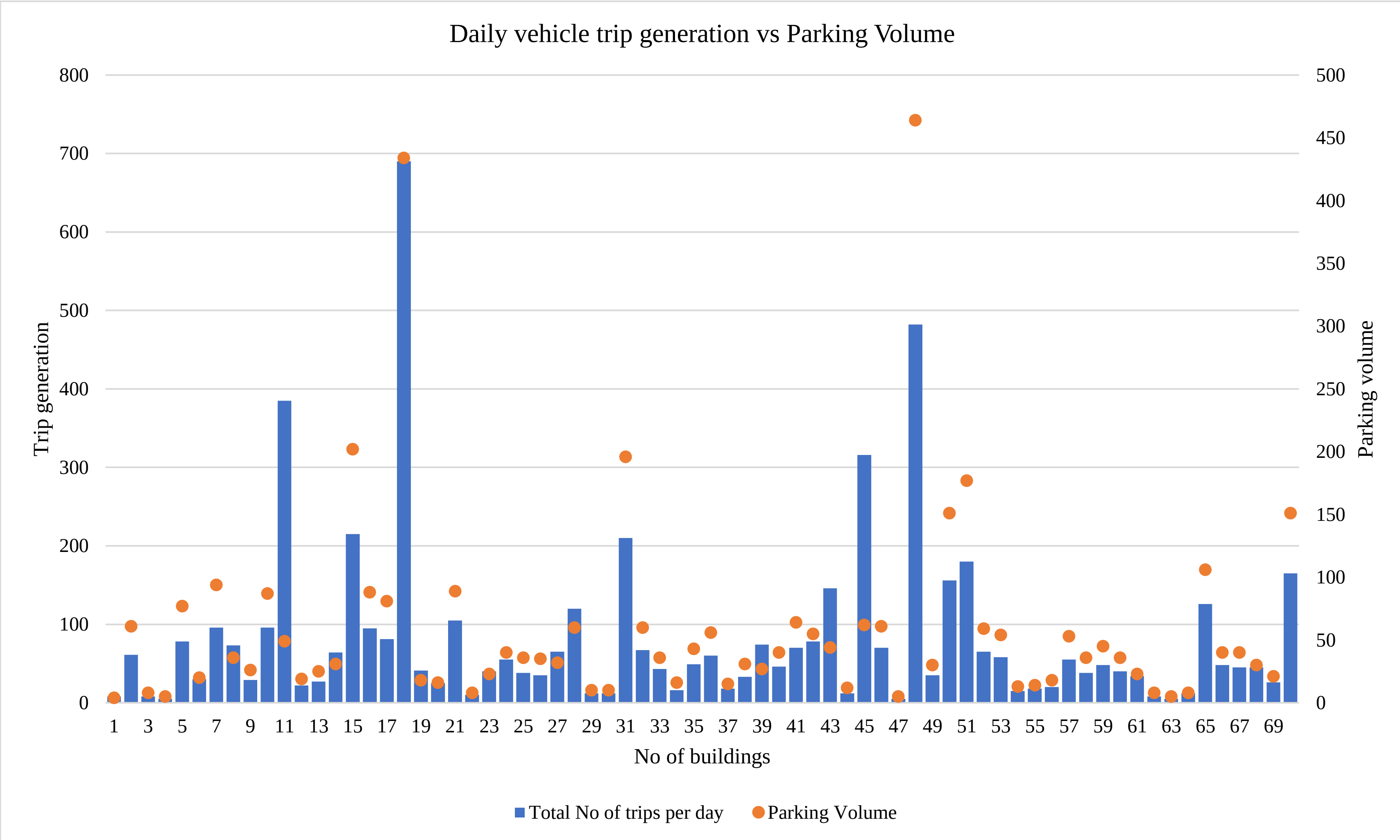

Figure 4.12: Distribution of daily vehicle trip generation vs parking volume

4.2.10 Variation in regulated parking requirement and parking allocation

According to the survey data analysis, it has been identified that there is a mismatch in between provided parking and regulated parking requirement. As per the UDA regulation, for office type development 1 for 150sqm parking space should be provided within the development (CCDP-2008). However, the survey data interpreted that, out of 70, 40 office buildings are provided excess parking spaces than the regulated requirement. 25 are provided parking in deficit the regulated requirement and 5 are provided equivalent parking spaces with the regulated parking requirement. These surveyed buildings have been explained there is a disparity between the supply and regulation requirement. Accordingly, providing excess parking space emphasizes that the regulations do not full fill the actual need (actual demand) of a development. Providing excess parking space means, the developers do not concern about the regulation requirements since they need more or less parking spaces to address the actual demand. Simply they ignore the current parking regulations and just to adopt with the approval process. Then, based on the requirements of the office (number of customers, number of staff, type of service, trip purposes, etc.,) the parking provisions should be designed. Figure 4.13 shows the variance in regulated parking requirement and actual parking allocation.

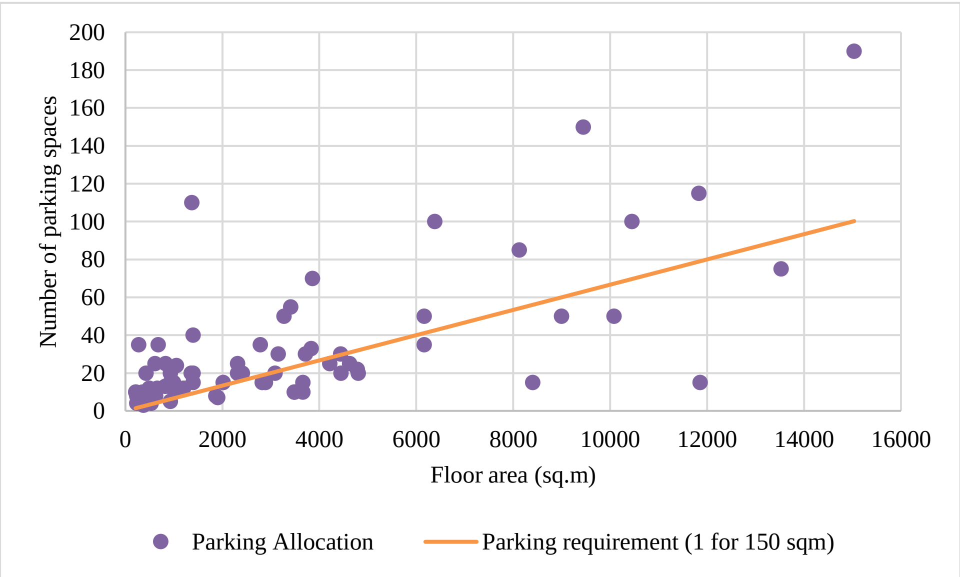

Figure 4.13: Variation in regulation requirement and parking allocation

Similarly, variance between parking demand and parking allocation was graphed as mentioned in the figure 4.14. The initial analysis of 70 office buildings, has revealed that actual parking demand and parking allocation are not match with each other.

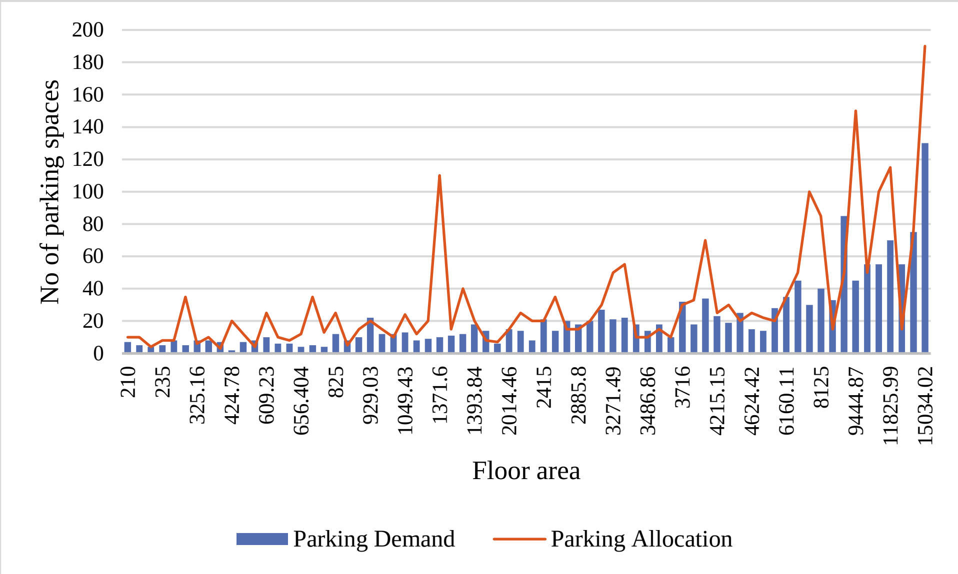

Figure 4.14: Variance between parking demand and parking allocation

4.2.11 Variation of daily vehicle trip generation vs parking demand

Figure 4.15 illustrates the relationship between vehicle trip generation and parking demand. It has been obtained 0.82 strong positive correlation and at the same time, it earned 0.67 R^2 value.

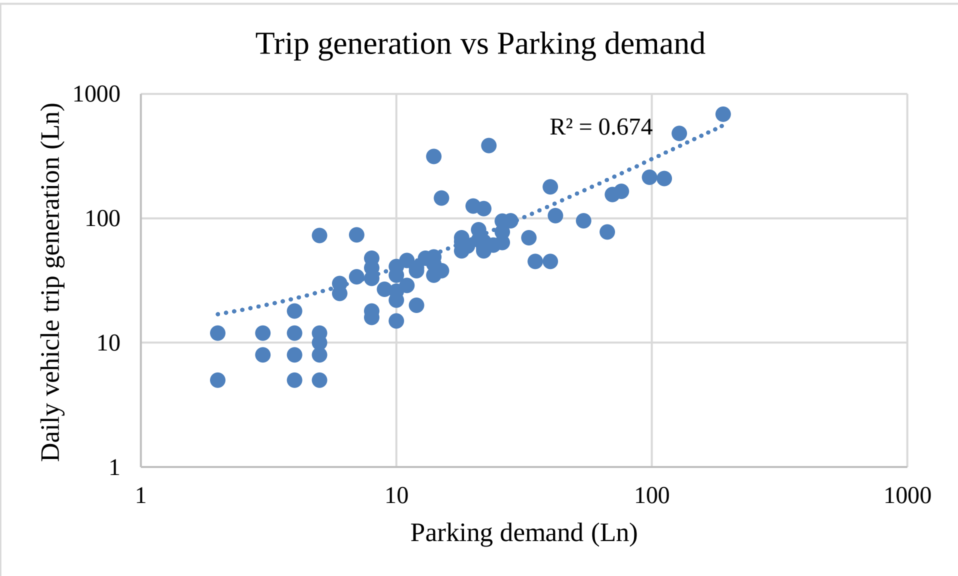

Figure 4.15: Relationship between vehicle trip generation and parking demand

4.2.12 Variation of dependent (trip generation) with independent variable (floor area, employees, service population, parking capacity)

To identify the variation pattern of the dependent (vehicle trip generation) and independent variables (service population, employees, floor area, parking capacity) which were selected using the AHP technique was analyzed in figure 4.16 to figure 4.19.

4.2.12.1 Variation of floor area with daily trip generation

Figure 4.16 illustrates the variation of floor area and daily vehicle trip generation. The R^2 value of this relationship is 0.47 and the correlation value is 0.605 with a positive linear relationship.

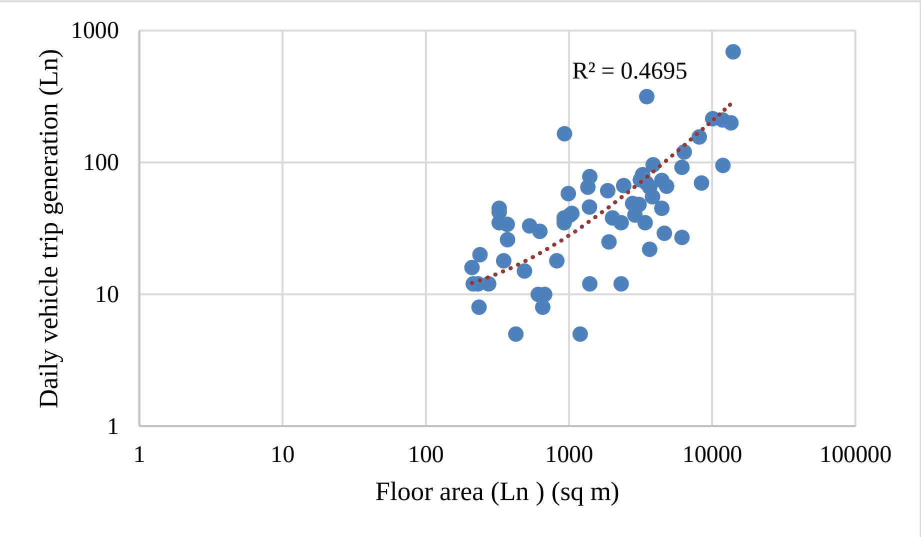

Figure 4.16: Variation of floor area with daily vehicle trip generation

4.2.12.2 Variation of employee population with daily trip generation

Figure 4.17 illustrates the variation of the number of employees and the daily vehicle trip generation. It has earned 0.75 R^2 value and 0.76 correlation value with a positive linear relationship between the selected two variables.

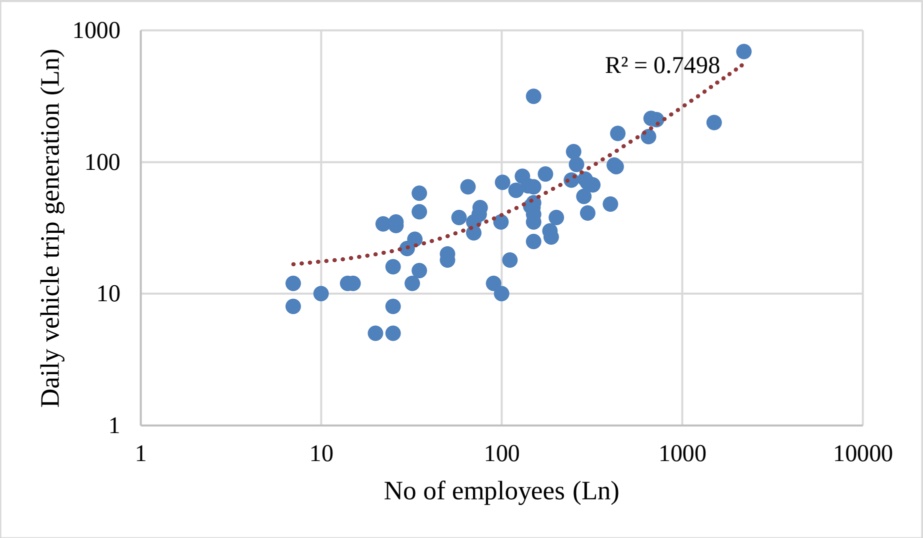

Figure 4.17: Variation of employee population with daily vehicle trip generation

4.2.12.3 Variation of service population with daily vehicle trip generation

Figure 4.18 demonstrates the variation of the service population (visitors) and the daily vehicle trip generation. It has mentioned 0.74 R^2 value while the correlation represents 0.79 value with a positive linear relationship.

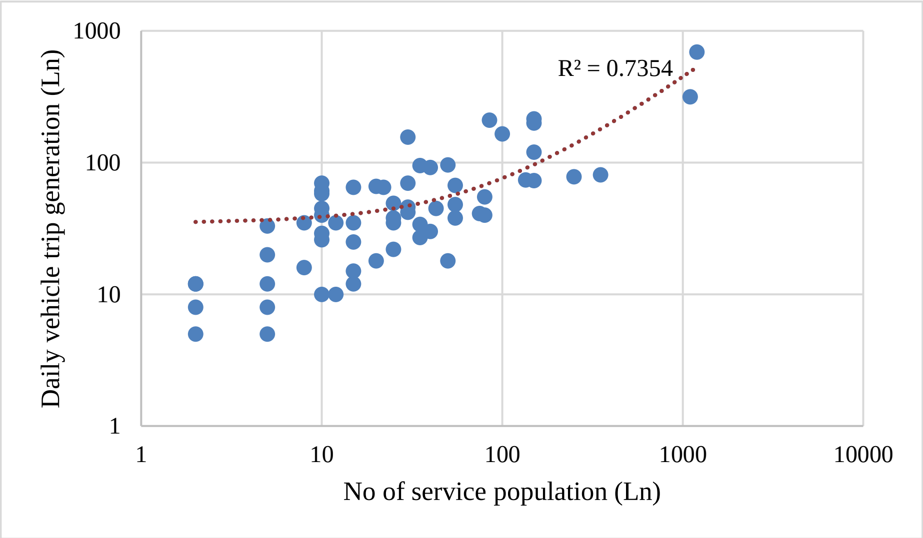

Figure 4.18: Variation of service population with daily vehicle trip generation

4.2.12.4 Variation of parking capacity with daily vehicle trip generation

Figure 4.19 illustrates the variation of parking capacity (available parking slots) and the daily vehicle trip generation. The R^2 value of this relationship is 0.70 and the correlation value is 0.75. The relationship between two variables has revealed the positive linear relationship.

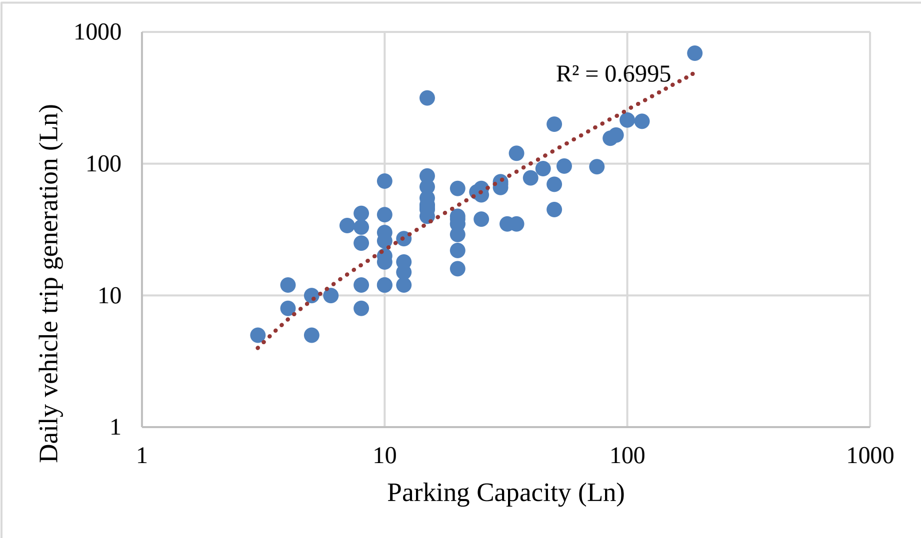

Figure 4.19: Variation of parking capacity with daily vehicle trip generation

The results revealed that there is a positive linear relationship between the dependent (vehicle trip generation) and independent variables. Thus, the service population, employees and parking capacity earn more than 0.5 R^2 value while the floor area earns 0.47 R^2 value. In addition to that, the correlation between dependent and independent variables also show a reasonable relationship than the floor area.

4.2.13 Variation of dependent (Parking demand) with independent variable (floor area, employees, service population)

To identify the variation pattern of the dependent (parking demand) and independent variables (service population, employees, floor area) which were selected using the AHP technique, was illustrated in figure 4.20 to figure 4.22.

4.2.13.1 Variation of floor area with parking demand

Figure 4.20 illustrates the variation of floor area with parking demand. The R^2 value of this relationship is 0.81 and the correlation value is 0.54 with a positive linear relationship.

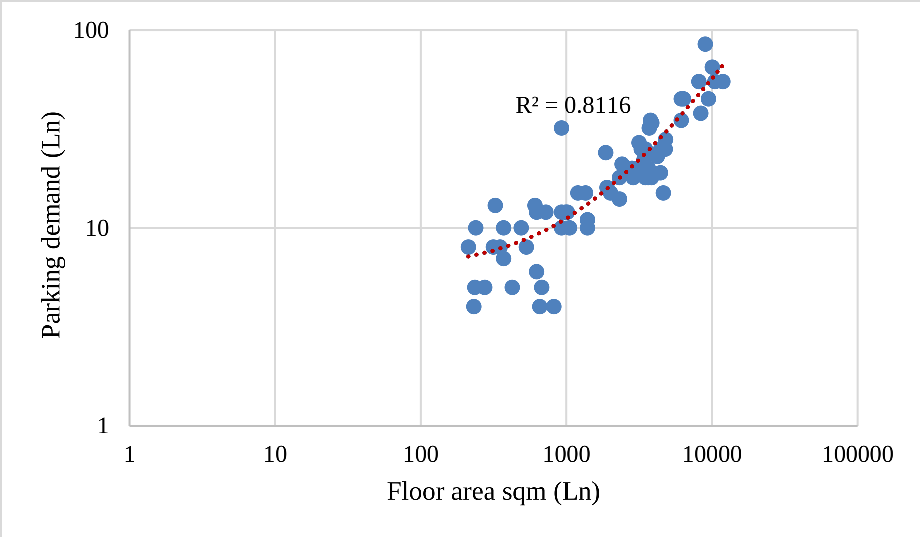

Figure 4.20: Scatter plot of floor area with parking demand

4.2.13.2 Variation of employee population with parking demand

Figure 4.21 illustrates the variation of employees with parking demand. It has earned 0.77 R^2 value and 0.816 correlation value with a positive linear relationship between the selected two variables.

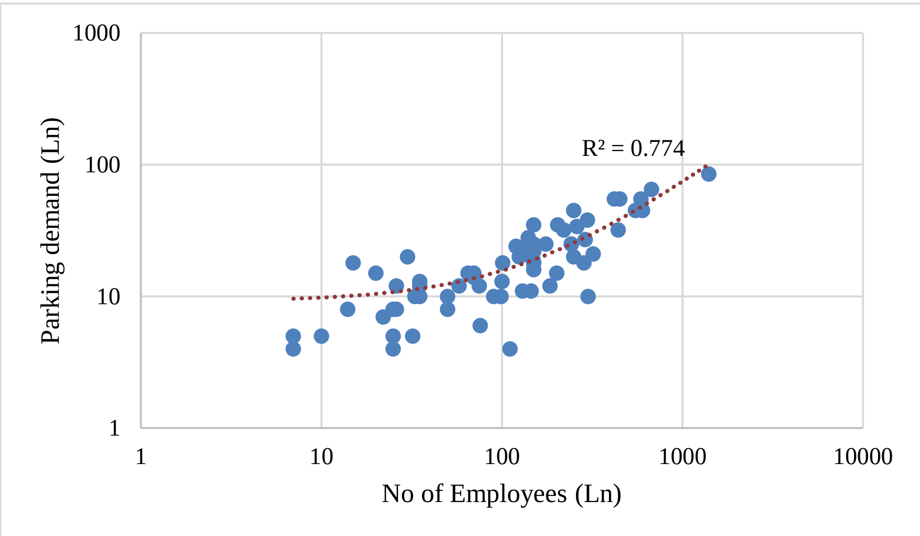

Figure 4.21: Scatter plot of employee population with parking demand

4.2.13.3 Variation of service population with parking demand

Figure 4.22 demonstrates the variation of service population (visitors) with parking demand. It has mentioned 0.32 R^2 value while the correlation represents 0.468 value with a linear relationship.

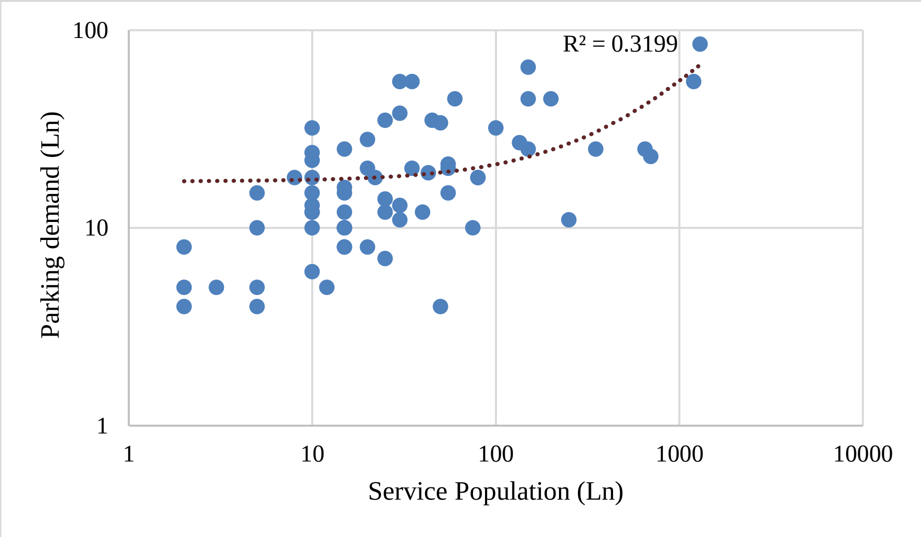

Figure 4.22: Scatter plot of service population with parking demand

The results revealed that there is a positive linear relationship between the dependent (Parking demand) and independent variables. Thus, the floor area and employees earn more than 0.5 R^2 value while the service population earns 0.32 R^2 value. In addition to that, the correlation between dependent and independent variables also show a reasonable relationship than the service population.

4.3 Model formulation

To formulate the daily vehicle trip generation model and parking demand model, 70 buildings were divided in to two main parts based on the ownership of the building. Government and Semi- Government buildings have been taken as a one category and private owned office buildings have taken as another category. Based on the ownership classification, the SPSS analysis was conducted. The classification details are mentioned in table 4.6.

Table 4.6: Model Classification

Category	Sample Size	Total Sample
Government + Semi Government	49	70
Private	21	70

Based on the surveys carried out, the available data are within the limits as described in table 4.7.

Table 4.7: Model parameter limits

Parameter	Minimum value limit	Maximum value limit
Floor area	200 sqm	15000 sqm
Employee	10	2000
Service population	5	1500
Parking Capacity	5	200

4.3.1 Daily Vehicle Trip generation model for Government and Semi-Government offices

To formulate the daily vehicle trip generation model for government and semi-government office developments, SPSS multiple linear regression analysis was used on the data set which was collected using an In and Out survey. There were 49 samples of office buildings. Table 4.8 illustrates the correlation coefficients in every five variables.

Table 4.8: Correlation

		Parking Capacity	Floor area sq.m	Employees	Service Population per day	No of trips per day
Parking Capacity	Pearson Correlation	1	.688**	.695**	.269	.596**
	Sig. (2-tailed)		.000	.000	.062	.000
	N	49	49	49	49	49
Floor area sq.m	Pearson Correlation	.688**	1	.760**	.340*	.483**
	Sig. (2-tailed)	.000		.000	.017	.000
	N	49	49	49	49	49
Employees	Pearson Correlation	.695**	.760**	1	.464**	.570**
	Sig. (2-tailed)	.000	.000		.001	.000
	N	49	49	49	49	49
Service Population per day	Pearson Correlation	.269	.340*	.464**	1	.795**
	Sig. (2-tailed)	.062	.017	.001		.000
	N	49	49	49	49	49
No of trips per day	Pearson Correlation	.596**	.483**	.570**	.795**	1
	Sig. (2-tailed)	.000	.000	.000	.000	
	N	49	49	49	49	49

According to the results, correlations are significant at level 0.01.

In order to conduct the analysis SPSS, stepwise method has been used. In the initial stage, all 49 data were entered and identified the outcomes. Subsequently in each step outliers were identified and detached. As final, the model was developed using 47 samples out of 49.

Floor area, Employees, Service population and Parking capacity has been entered as independent variables which were selected using AHP and ultimately it has developed two models.

- Model 1: Daily vehicle trip generation = (Constant)+ Service Population
- Model 2: Daily vehicle trip generation = (Constant)+ Service population + Parking Capacity

Table 4.9: Model Summaries

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.880[a]	.774	.769	40.422	
2	.948[b]	.898	.893	27.469	1.880

a. Predictors:(Constant), Service Population

b. Predictors: (Constant), Service Population, Parking Capacity

c. Dependent Variable: Daily vehicle trip generation

Considering the model results second model is selected as a final model since it is able to capture 89% amount of variability with the 95% confidence interval. The selected model earned 0.94 R-value, 0.89 R2 value and 1.88 Durbin-Watson value. Table 4.10 describes the coefficient values of the selected model.

Table 4.10: Coefficient

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
2	(Constant)	15.230	5.844		2.606	.012
	Service Population	.230	.018	.700	12.946	.000
	Parking Capacity	1.043	.143	.395	7.311	.000

Dependent Variable: Daily vehicle Trip generation

To formulate this model, four independent variables were entered and ultimately it has excluded “Employees and Floor area” variables from the final regression model. Then the final regression model has been formulated using Service Population and Parking capacity. All the values were significantly different from zero ($P<0.05$ and t value) of the developed model. The final output of the regression analysis is explained in the table 4.10.

The derived formula for estimating daily vehicle trip generation of government + semi-government office developments is described in equation 16.

*Daily vehicle trip generation= 15.23+ [(0.230*Service Population) + (1.043*Parking Capacity)]* (16)

4.3.2 Daily vehicle trip generation model for Private office buildings

To formulate the daily vehicle trip generation model for private office developments, SPSS multiple linear regression analysis was used on the data set which was collected using an In and Out surveys. There were 21 sample of office buildings. Table 4.11 illustrates the correlation in every five variables.

Table 4.11: Correlations

		Parking Capacity	Floor area sq.m	Employees	Service Population per day	No of trips per day
Parking Capacity	Pearson Correlation	1	.836**	.924**	.831**	.935**
	Sig. (2-tailed)		.000	.000	.000	.000
	N	21	21	21	21	21
Floor area sq.m	Pearson Correlation	.836**	1	.955**	.950**	.968**
	Sig. (2-tailed)	.000		.000	.000	.000
	N	21	21	21	21	21
Employees	Pearson Correlation	.924**	.955**	1	.964**	.980**
	Sig. (2-tailed)	.000	.000		.000	.000
	N	21	21	21	21	21
Service Population per day	Pearson Correlation	.831**	.950**	.964**	1	.930**
	Sig. (2-tailed)	.000	.000	.000		.000
	N	21	21	21	21	21
No of trips per day	Pearson Correlation	.935**	.968**	.980**	.930**	1
	Sig. (2-tailed)	.000	.000	.000	.000	
	N	21	21	21	21	21

According to the results, correlations are significant at level 0.01.

In order to conduct the analysis, SPSS stepwise method has been used. To formulate the regression model, 21 samples were used.

Floor area, Employees, Service population and Parking Capacity has been entered as independent variables which were selected using AHP and ultimately it has developed four models.

- Model 1: Daily vehicle trip generation= (Constant)+ Employees
- Model 2: Daily vehicle trip generation= (Constant)+ Employees + Floor area

- Model 3: Daily vehicle trip generation= (Constant)+ Employees + Floor area + Parking Capacity
- Model 4: Daily vehicle trip generation= (Constant) + Floor area + Parking Capacity

Table 4.12: Model Summaries

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.980[a]	.961	.959	30.204	
2	.986[b]	.973	.970	25.992	
3	.995[c]	.990	.988	16.067	
4	.995[d]	.990	.989	15.851	1.870

a. Predictors: (Constant), Employees

b. Predictors: (Constant), Employees, Floor area sq.m

c. Predictors: (Constant), Employees, Floor area sq.m, Parking Capacity

d. Predictors: (Constant), Floor area sq.m, Parking Capacity

e. Dependent Variable: Daily vehicle trip generation

Considering the model results second model is selected as a final model since it is able to capture 97% amount of variability with the 95% confidence interval. The selected model earned 0.98 R-value, 0.97 R^2 value. Table 4.13 describes the coefficient values of the selected model.

Table 4.13: Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
2	(Constant)	15.992	6.915		2.313	.033
	Employees	.199	.041	.633	4.809	.000
	Floor area sq.m	.018	.006	.364	2.767	.013

Dependent Variable: Daily vehicle trip generation

To formulate this model, four independent variables were entered and ultimately it has excluded “Service population and Parking Capacity” from the final regression model. The final regression model has been formulated using employees and Floor area. All the values were significantly different from zero (P<0.05 and t value) of the developed model. The final output of the regression analysis is explained in the table 4.13.

The derived formula for estimating daily vehicle trip generation for private office developments are described in equation 17.

*Daily vehicle trip generation= 15.99+(0.199*Employees) + (0.018*Floor area)*
(17)

4.3.3 Parking demand model for Government and Semi-Government Office buildings

To formulate the parking demand model for government and semi- government office developments, SPSS multiple linear regression analysis was used on the data set which was collected using an In and Out survey. There was 49 sample of office buildings. Table 4.14 illustrates the correlation coefficients in every four variables.

Table 4.14: Correlations

		Floor area sq.m	Employees	Service Population per day	Parking Demand
Floor area sq.m	Pearson Correlation	1	.760**	.340*	.640**
	Sig. (2-tailed)		.000	.017	.000
	N	49	49	49	49
Employees	Pearson Correlation	.760**	1	.464**	.721**
	Sig. (2-tailed)	.000		.001	.000
	N	49	49	49	49
Service Population per day	Pearson Correlation	.340*	.464**	1	.324*
	Sig. (2-tailed)	.017	.001		.023
	N	49	49	49	49
Parking Demand	Pearson Correlation	.640**	.721**	.324*	1
	Sig. (2-tailed)	.000	.000	.023	
	N	49	49	49	49

According to the results, correlations are significant at level 0.01.

In order to conduct the analysis SPSS, the stepwise method has been used. In the first stage, all 49 data were entered and identified the outcomes. Subsequently in each step outliers were identified and detached. The final, the model was developed using 47 samples out of 49.

Floor area, employees and Service population has been entered as independent variables which were selected using AHP and ultimately it has developed a model.

- Model 1: Parking demand= (Constant)+ Employees

Table 4.15: Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.733[a]	.538	.528	15.005	1.626

a. Predictors: (Constant), Employees

b. Dependent variable: Parking Demand

The model results show it is able to capture 54% amount of variability with the 95% confidence interval. The selected model earned 0.73 R-value, 0.54 R^2 value. Table 4.16 describes the coefficient values of the selected model.

Table 4.16: Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	7.223	2.827		2.555	.014
	No of Employees	.050	.007	.733	7.236	.000

To formulate this model, three independent variables were entered and ultimately it has excluded "Service population and Floor area" from the final regression model. Then the final regression model has been formulated using "employees". All the values were significantly different from zero ($P<0.05$ and t value) of the developed model. The final output of the regression analysis is explained in the table 4.16.

The derived formula for estimating parking demand for government + semi-government office developments is described in equation 18.

$$\textit{Parking Demand} = 7.22+(0.50*\textit{Employees}) \qquad (18)$$

4.3.4 Parking demand model for Private Office buildings

To formulate the parking demand model for private office developments, SPSS multiple linear regression analysis was used on the data set which was collected using an In and Out surveys. There was 21 sample of office buildings. Table 4.17 illustrates the correlations of every four variables.

Table 4.17: Correlations

		Floor area sq.m	Employees	Service Population per day	Parking Demand
Floor area sq.m	Pearson Correlation	1	.955**	.950**	.895**
	Sig. (2-tailed)		.000	.000	.000
	N	21	21	21	21
Employees	Pearson Correlation	.955**	1	.964**	.960**
	Sig. (2-tailed)	.000		.000	.000
	N	21	21	21	21
Service Population per day	Pearson Correlation	.950**	.964**	1	.896**
	Sig. (2-tailed)	.000	.000		.000
	N	21	21	21	21
Parking Demand	Pearson Correlation	.895**	.960**	.896**	1
	Sig. (2-tailed)	.000	.000	.000	
	N	21	21	21	21

According to the results, correlations are significant at level 0.01.

In order to conduct the analysis, SPSS stepwise method has been used. To formulate the regression model 21 sample were used.

Floor area, employees and Service population has been entered as independent variables which were selected using AHP and ultimately it has developed a model.

- Model 1: Parking Demand= (Constant)+ Employees

Table 4.18: Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.960[a]	.921	.917	12.023	1.610

a. Predictors: (Constant), Employees

b. Dependent variable: Parking Demand

The model results show, it is able to capture 92% amount of variability with the 95% confidence interval. The selected model earned 0.96 R-value, 0.92 R2 value. Table 4.19 describes the coefficient values of the selected model.

Table 4.19: Coefficient

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	10.991	2.798		3.928	.001
	No of Employees	.084	.006	.960	14.926	.000

To formulate this model, three independent variables were entered and ultimately it has excluded “Service population and Floor area” from the final regression model. The final regression model has been formulated using “employees”. All the values were significantly different from zero ($P<0.05$ and t value) of the developed model. The final output of the regression analysis is explained in the table 4.19.

The derived formula for estimating parking demand for private office developments is described in equation 19.

*Parking Demand= 10.99+(0.84*Employees)* (19)

4.3.5 Examine the effectiveness of developed models

The model formulation was conducted based on the ownership classification of office developments. Total 49 government + semi-government offices and 21 private offices were taken for both vehicle trip generation and parking demand estimation models.

4.3.5.1 Daily vehicle trip generation model for Government and Semi-Government offices

According to the analysis, the derived formula for estimating daily vehicle trip generation for Government and Semi-Government offices is described in equation 16.

*Daily vehicle trip generation= 15.23+ (0.230*Service Population) + (1.043*Parking Capacity)* (16)

As per the formula, the variation between actual and estimated values was displayed in figure 4.23.

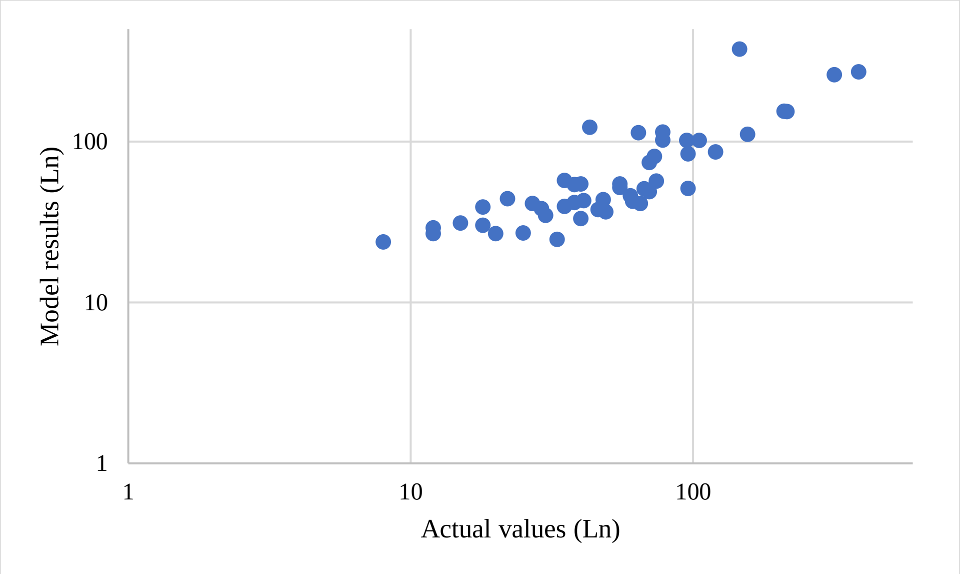

Figure 4.23: Scatter plot of actual and estimated values (Trip generation of Government & Semi-Government office developments)

4.3.5.2 Daily vehicle trip generation model for Private office buildings

According to the analysis, the derived formula for estimating daily vehicle trip generation for private office developments is described in equation 17.

Daily vehicle trip generation=15.99+(0.199 Employees) +(0.018*Floor area)* (17)

As per the formula, the variation between actual and estimated values was displayed in figure 4.24.

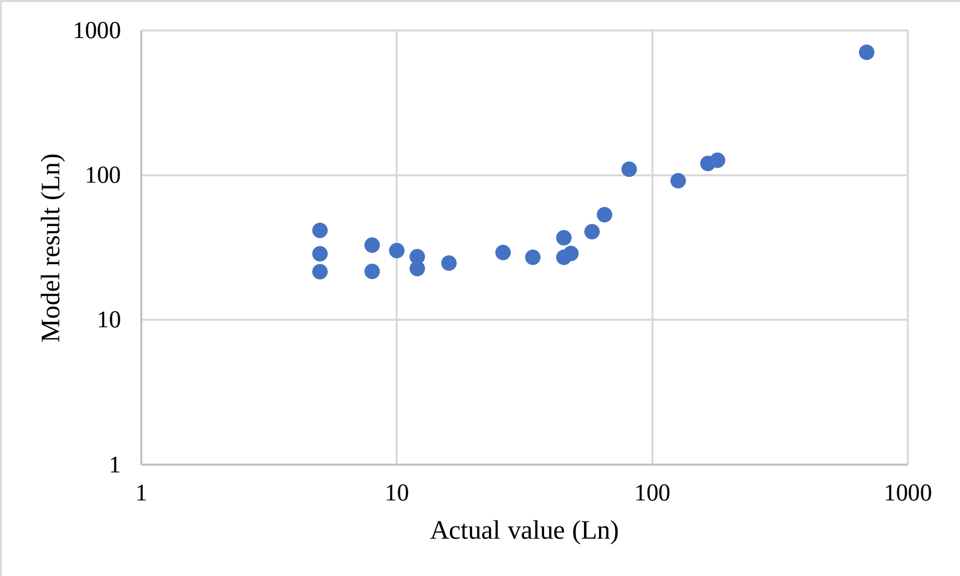

Figure 4.24: Scatter plot of actual and estimated values (Vehicle Trip generation of private office developments)

4.3.5.3 Parking demand model for Government and Semi-Government Office buildings

According to the analysis, the derived formula for estimating parking demand for Government and Semi-Government offices is described in equation 18.

Parking Demand= 7.22+(0.50 Employees)* (18)

As per the formula, the variation between actual and estimated values was displayed in figure 4.25.

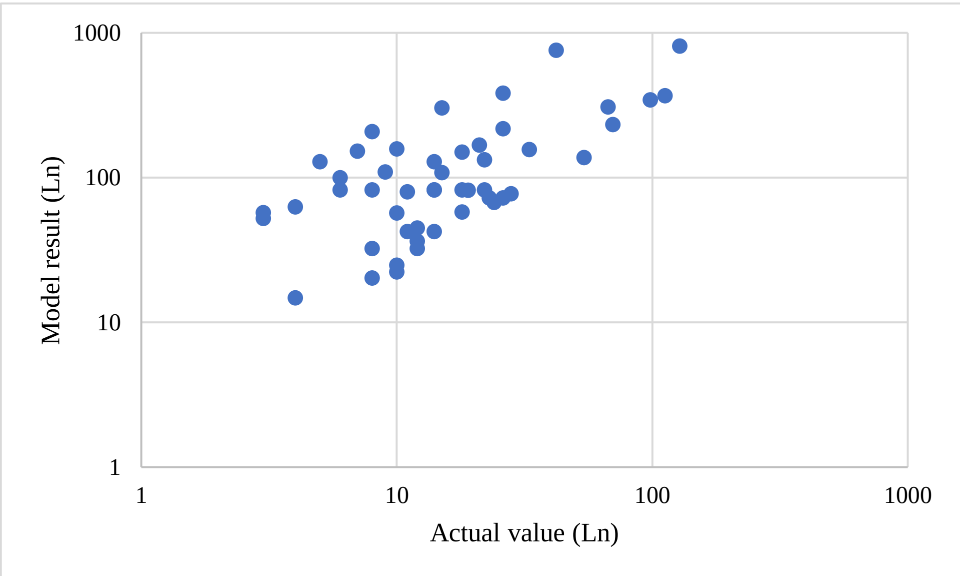

Figure 4.25: Scatter plot of actual and estimated values (Parking demand of Government & Semi-Government office developments)

4.3.5.4 Parking demand model for Private Office buildings

According to the analysis, the derived formula for estimating parking demand for private office developments is described in equation 19.

Parking Demand= 10.99+(0.84 Employees)* (19)

As per the equation, the variation between actual and estimated values was displayed in figure 4.26.

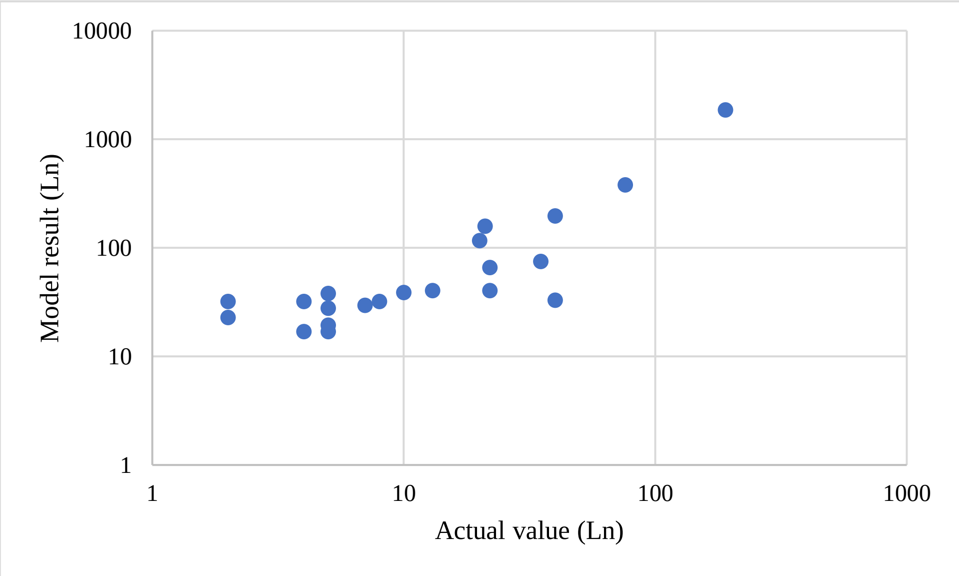

Figure 4.26: Scatter plot of actual and estimated values (Parking demand of Private office developments)

The study has developed four different regression models to estimate daily vehicle trip rates and parking demand in both government and private office developments. According to the analysis, some limitations can be identified.

The intercept values of daily vehicle trip generation model for Government and Semi-Government offices (15.23), daily vehicle trip generation model for Private office buildings (15.99), Parking demand model for Government and Semi-Government Office buildings (7.22), Parking demand model for private Office buildings (10.99) were relatively high. Therefore, there was a large difference in between estimated and actual values.

As per the Central Limit Theorem which justifies the use of normal distribution, if the sample size is large enough. Empirically, it's said to be enough if the sample size is greater than 30. So, the minimum 30 sample is considered when conducting a test. When it comes to this analysis, to formulate daily vehicle trip generation model and parking demand model of private offices use 21 samples.

By analyzing the Scatter plots (figure 4.23- 4.26) show that the model results are not perfectly predicted. It shows there were some errors in predicted values. By considering the situation the developed four different models are not “best fit” ones. Therefore, this study ignored the developed four regression models and developed another two regression models by taking total 70 samples.

4.3.6 Model formulation for Daily vehicle trip generation

To formulate the daily vehicle trip generation model, SPSS multiple linear regression analysis was used on the data set which was collected using an In and Out survey. There was 70 sample of office buildings. Table 4.20 illustrates the correlation values of every five variables.

Table 4.20: Correlation

		Floor area sq.m	Parking Capacity	Employees	Service Population per day	No of Trips per day
Floor area (sq.m)	Pearson Correlation	1	.696**	.795**	.476**	.605**
	Sig. (2-tailed)		.000	.000	.000	.000
	N	70	70	70	70	70
Parking Capacity	Pearson Correlation	.696**	1	.799**	.430**	.758**
	Sig. (2-tailed)	.000		.000	.000	.000
	N	70	70	70	70	70
Employees	Pearson Correlation	.795**	.799**	1	.602**	.767**
	Sig. (2-tailed)	.000	.000		.000	.000
	N	70	70	70	70	70
Service Population per day	Pearson Correlation	.476**	.430**	.602**	1	.793**
	Sig. (2-tailed)	.000	.000	.000		.000
	N	70	70	70	70	70
No of Trips per day	Pearson Correlation	.605**	.758**	.767**	.793**	1
	Sig. (2-tailed)	.000	.000	.000	.000	
	N	70	70	70	70	70

According to the results, correlations are significant at level 0.01.

In order to conduct the analysis, SPSS stepwise method has been used. In the first stage, all 70 data were entered and identified the outcomes. Subsequently in each step outliers were identified and detached. Ultimately, the final regression model was developed using 63 samples out of 70.

Floor area, Employees, Service population and Parking capacity has been entered as independent variables which were selected using AHP and ultimately it has developed three models.

- Model 1: Daily vehicle trip generation= (Constant)+ Employee
- Model 2: Daily vehicle trip generation = (Constant)+ Employee+ Service population
- Model 3: Daily vehicle trip generation = (Constant)+Employee+ service population+ parking capacity

Table 4.21 ANOVA table describes the results of the developed three models. All three models are significant since they earn less than 0.05 P-value. As well, significant F values. As per the results, the first model excluded service population, floor area and parking capacity, the second model excluded parking capacity and floor area, third model excluded floor area. Table 4.22 represents model summaries in each model. Model 1 captured 75% amount of variability, model 2 captured 93% amount of variability and model 3 captured 98% amount of variability.

Table 4.21: ANOVA Table for developed models

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	453454.736	1	453454.736	182.817	.000
	Residual	151302.692	61	2480.372		
	Total	604757.429	62			
2	Regression	564078.750	2	282039.375	416.001	.000
	Residual	40678.679	60	677.978		
	Total	604757.429	62			
3	Regression	591297.269	3	197099.090	863.946	.000
	Residual	13460.160	59	228.138		
	Total	604757.429	62			

Table 4.22: Model Summaries

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.866[a]	.750	.746	49.803	
2	.966[b]	.933	.930	26.038	
3	.989[c]	.978	.977	15.104	2.071

a. Predictors: (Constant), Employee

b. Predictors: (Constant), Employee, Service population

c. Predictors: (Constant), Employee, Service population, Parking capacity

d. Dependent variable: Daily vehicle trip generation

Considering the model results third model is selected as a final model since it is able to capture 98% amount of variability with the 95% confidence interval. The selected model earned 0.98 R-value, 0.98 R^2 value and 2.07 Durbin-Watson value. Table 4.23 describes the coefficient values of the selected model.

Table 4.23: Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
3	(Constant)	.511	.503		.201	.041
	Employee	.074	.010	.261	7.266	.000
	Service population	.251	.012	.521	21.609	.000
	Parking capacity	1.134	.104	.364	10.923	.000

Dependent Variable: Daily vehicle trip generation

Although four independent variables were used to form a model, the model excluded the variable “Floor area” due to the insignificance of P-value which marked as 0.514. If the P-value is greater than or equal to 0.05, it revealed that the selected variable has no significant association with the response variable and that model is not suitable for prediction. If the P-value is less than 0.05, it revealed that the model is able to explain a significant amount of total observed variability. Therefore, excluding the floor area, it was selected employees, service population and parking capacity as independent variables for final output. All the values were significantly different from zero ($P<0.05$ and t value). The final output of the regression analysis is explained in the table 4.22.

The derived formula for estimating daily vehicle trip generation for urban office developments is described in equation 20.

*Daily vehicle trip generation= 0.511+(0.074*Employees) + (0.251*Service population) +(1.134*Parking capacity)* (20)

Formerly the residuals have been checked to identify the significant relationship among errors. Durbin Watson (DW) statistic is used to detect the presence of autocorrelation of lag 1 in the residuals (prediction errors) from a regression analysis. DW value should be close to 2. The model earned 2.071 DW value which closes to 2. Therefore, the value suggested that errors are random as it is close to 2. That means the residuals are randomly behaved. Table 4.24 illustrates the DW value. The Shapiro- Wilk test should not be significant ($p>5\%$) when the data follow the normal distribution. As per the definition, the illustrates P-value as 0.247 ($p=0.247$) which is Shapiro- Wilk test is not significant. Therefore, it can be identified that the errors are distributed randomly and significantly different from the normal distribution. Table 4.25 represents the results. Table 4.26 represents with the 95% confident interval of the residual means laid in between -3.71 lower bound and 3.71 upper bound. The observed mean residuals are 0.00 and it means residual means are not significantly different from zero ($P=1.0$)

Table 4.24: Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.866[a]	.750	.746	49.803	
2	.966[b]	.933	.930	26.038	
3	.989[c]	.978	.977	15.104	2.071

a. Predictors: (Constant), Employee
b. Predictors: (Constant), Employee, Service population
c. Predictors: (Constant), Employee, Service population, Parking capacity
d. Dependent variable: Daily vehicle trip generation

Table 4.25: Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Unstandardized Residual	.066	63	.200*	.976	63	.247

Figure 4.27 illustrates the distribution of histogram for unstandardized residuals.

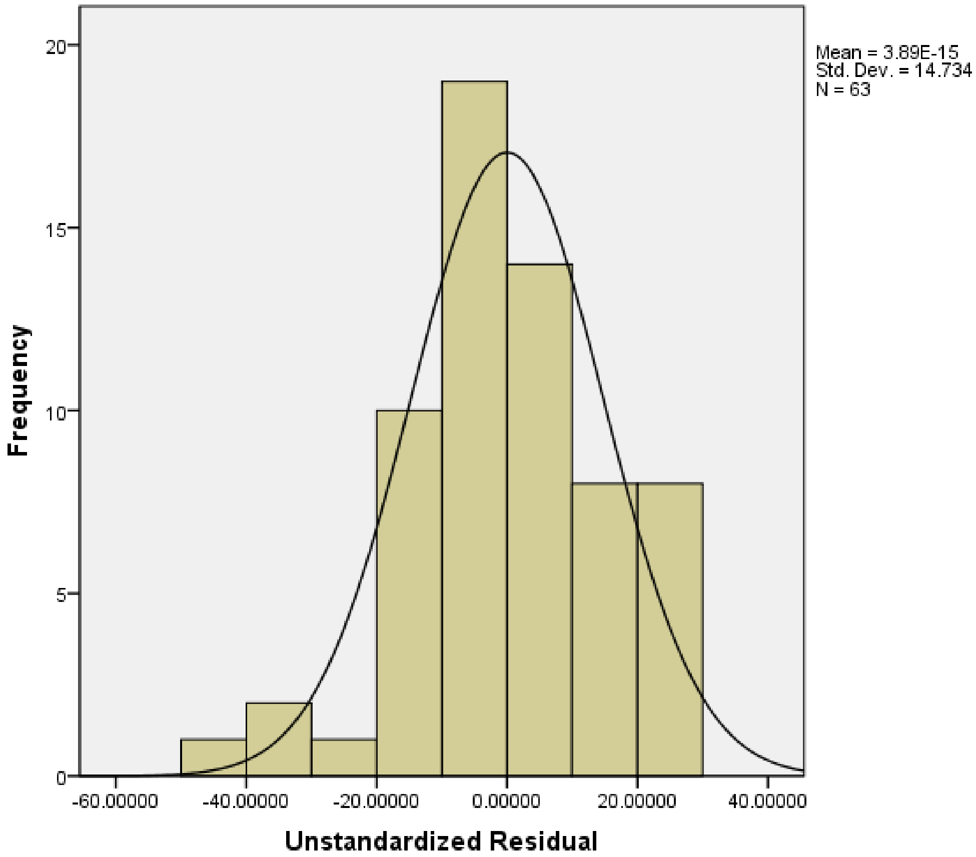

Figure 4.27: Regression unstandardized residual

Table 4.26: One-Sample Test

	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference Lower	95% Confidence Interval of the Difference Upper
Unstandardized Residual	.000	62	1.000	.00000000	-3.7107833	3.7107833

4.3.7 Model formulation for Parking demand

To formulate the parking demand model SPSS multiple linear regression analysis was used on the data set which was collected using an In and Out surveys. There was 70 sample of office buildings. Table 4.27 illustrates the correlation values of the selected four variables.

Table 4.27: Correlations

		Floor area sq.m	Employees	Service Population per day	Parking Demand
Floor area sq.m	Pearson Correlation	1	.798**	.514**	.811**
	Sig. (2-tailed)		.000	.000	.000
	N	70	70	70	70
Employees	Pearson Correlation	.798**	1	.666**	.774**
	Sig. (2-tailed)	.000		.000	.000
	N	70	70	70	70
Service Population per day	Pearson Correlation	.514**	.666**	1	.319**
	Sig. (2-tailed)	.000	.000		.000
	N	70	70	70	70
Parking Demand	Pearson Correlation	.811**	.774**	.319**	1
	Sig. (2-tailed)	.000	.000	.000	
	N	70	70	70	70

According to the results, correlations are significant at level 0.01.

In order to conduct the analysis, SPSS stepwise method has been used. In the first stage, all 70 data were entered and identified the outcomes. Subsequently in each step outliers were identified and detached. Ultimately, the model was developed using 67 samples out of 70.

Floor area, Employees, Service population has been entered as independent variables which were selected using AHP and ultimately it has developed two models.

- Model 1: Parking demand= (Constant)+ Floor area
- Model 2: Parking demand= (Constant)+ Floor area+ Employees

Table 4.28 ANOVA table describes the results of the developed two models. All two models are significant since they earn less than 0.05 P-value. As well, significant F values. As per the results, the first model excluded the service population and no of employees, the second model excluded the service population. Table 4.29 represents model summaries. Model 1 captured 81% amount of variability and model 2 captured 92% amount of variability.

Table 4.28: ANOVA Table for developed models

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	13959.300	1	13959.300	279.992	.000[a]
	Residual	3240.640	65	49.856		
	Total	17199.940	66			
2	Regression	15772.708	2	7886.354	353.640	.000[b]
	Residual	1427.232	64	22.301		
	Total	17199.940	66			

a. Predictors: (Constant), Floor area sq.m

b. Predictors: (Constant), Floor area sq.m, Employee

c. Dependent variable: Parking demand

Table 4.29: Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.901[a]	.812	.809	7.061	
2	.958[b]	.917	.914	4.722	1.949

a. Predictors: (Constant), Floor area sq.m

b. Predictors: (Constant), Floor area sq.m, Employee

c. Dependent variable: Parking demand

Considering the model results, the second model is selected as a final regression model since it has able to capture a 92% amount of variability with the 95% confidence interval. The selected regression model earned 0.96 R-value, 0.92 R^2 value and 1.94 Durbin-Watson value. Table 4.30 describes the coefficient values of the selected regression model.

Table 4.30: Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
2	(Constant)	5.438	.832		6.539	.000
	Floor area sq.m	.003	.000	.554	10.502	.000
	Employees	.035	.004	.475	9.018	.000

a. Dependent Variable: Parking Demand

It is observed that the independent variables in the regression model are statistically significant as the P-value is less than 0.05. Even three independent variables were used to form a model, as in the first stage it has excluded the "service population" due to insignificancy (P=0.908). Thus, this variable did not have a significant association with the response variable and that model is not suitable for prediction. Finally, by excluding independent variables "service population", the model was developed to estimate parking demand for urban office developments with Floor area and employees.

The derived formula for estimating parking demand for urban office developments is described in equation 21.

$$\textit{Parking demand} = 5.438 + (0.003 * \textit{Floor area}) + (0.035 * \textit{Employees}) \quad (21)$$

Again, the residuals have been checked to identify the significant relationship among errors. The model earned a 1.949 DW value which closes to 2. Therefore, the value suggested that errors are random as it is close to 2. It means the residuals randomly behave. P-value earns 0.316 (P=0.316) which is Shapiro- Wilk test is not significant as mentioned in Table 4.32. Therefore, it can be identified that the errors are distributed randomly and significantly different from the normal distribution. Table 4.33 displays with the 95% confident interval of the residual means laid in between -1.13 lower bound and 1.13 upper bound. The observed mean residuals are 0.00 and it means residual means are not significantly different from zero (P=1.0)

Table 4.31: Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.901[a]	.812	.809	7.061	
2	.958[b]	.917	.914	4.722	1.949

a. Predictors: (Constant), Floor area sq.m

b. Predictors: (Constant), Floor area sq.m, Employee

c. Dependent variable: Parking demand

Table 4.32: Test of Normality

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Unstandardized Residual	.084	67	.200*	.979	67	.316

a. Lilliefors Significance Correction

*. This is a lower bound of the true significance.

Figure 4.28 illustrates the distribution of histogram for unstandardized residuals.

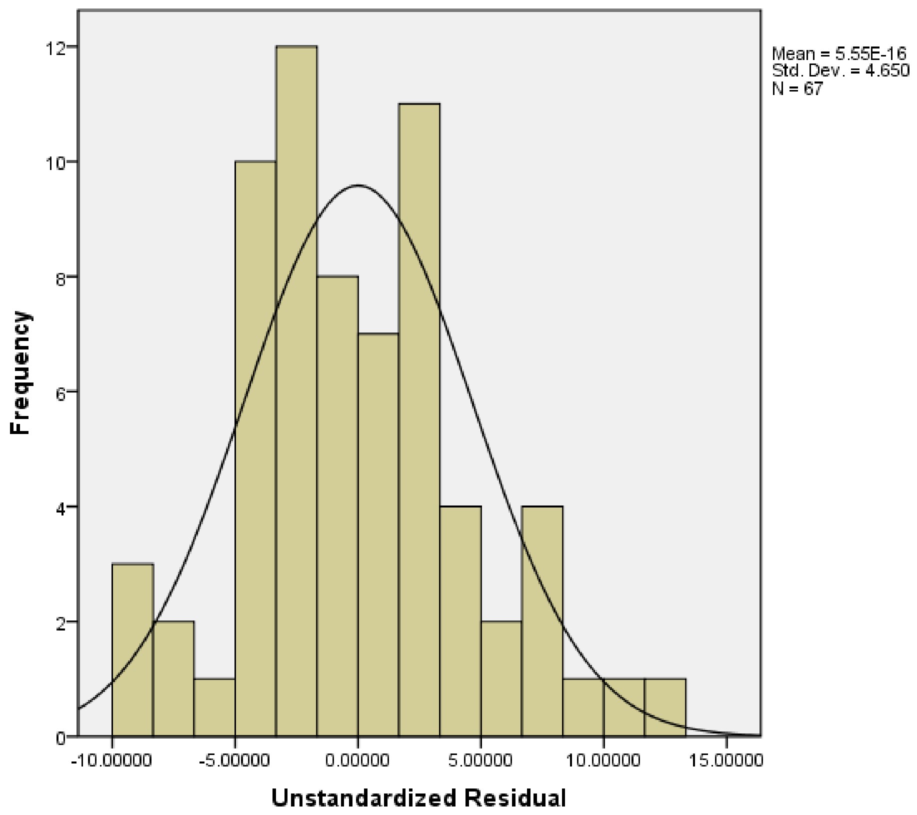

Figure 4.28: Regression Unstandardized Residual

Table 4.33: One-Sample Test

	Test Value = 0					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Unstandardized Residual	.000	66	1.000	.00000000	-1.1342827	1.1342827

Afterwards, obtaining the regression equation, the data were compared graphically with the regulation requirements and parking demand. Figure 4.29 and 4.30 illustrate the outcomes. The model is always behaved with the actual parking demand. It will be help to reduce excess parking spaces, reduce construction cost and help to save the precious land.

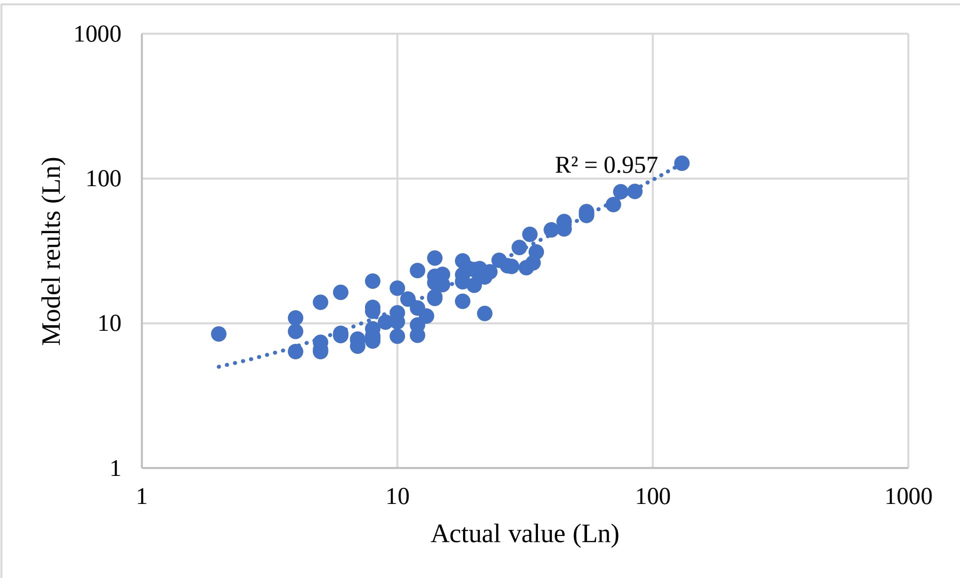

Figure 4.29:Variance between actual parking demand and model results

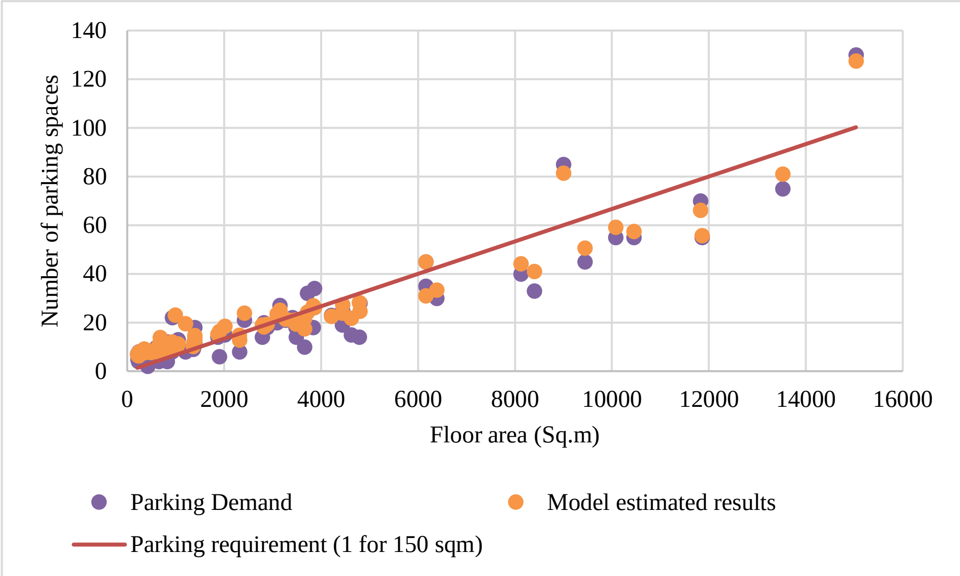

Figure 4.30: Variance between regulation requirement, parking demand and model results

4.4 Model Validation

To validate the developed two models, data were collected from Sri Jayawardhenapura Kotte Municipal Council area. 10 different government and private offices were selected for the validation (5 per each category).

4.4.1 Model Validation- Daily vehicle trip generation

To check the validity of the daily vehicle trip generation model, Mean Absolute Error and Mean Absolute Percentage Error was calculated in the sample data set between actual and predictors. According to the calculations MAE is estimated as 1.94 and MAPE is 19.91%. Lower MAPE percentage errors represent a more accurate forecast. Accordingly, the validity of the dataset is in the "good forecast" level (Chen, Bloomfield, & Fu, 2003). Equations of MAE and MAPE illustrate in Equation (11) and Equation (12) (Stellwagen, 2020) and figure 4.31 shows the relationship between actual and predicted values in the validation dataset.

MAE= (Actual value- Estimated value)/ Actual value (11)

*MAPE= (MAE/n) *100%* (12)

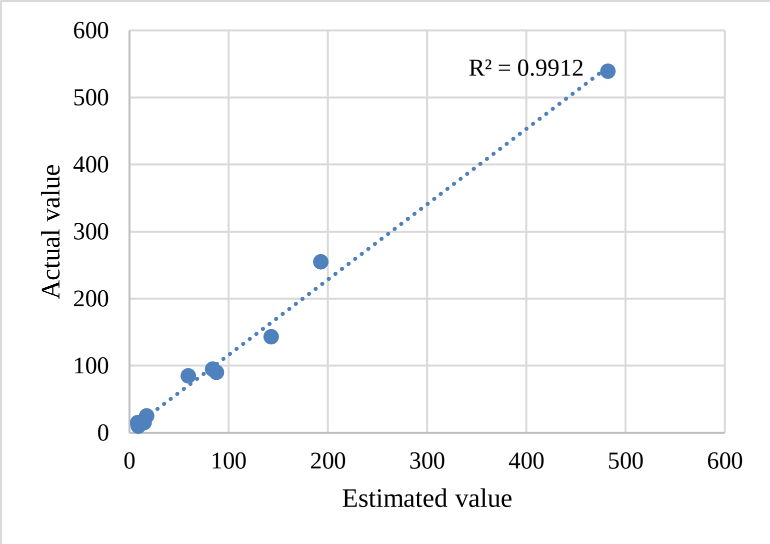

Figure 4.31: Relationship between actual and estimated values (daily vehicle trip generation)

4.4.2 Model Validation- Parking demand

To check the validity of peak parking demand model, Mean Absolute Error and Mean Absolute Percentage Error was calculated in sample data set between actual and predictors. According to the calculations MAE is estimated as 1.67 and MAPE is 16.75%. Lower MAPE percentage errors represent a more accurate forecast. Accordingly, the validity of the dataset is in the "good forecast" level (Chen, Bloomfield, & Fu, 2003). Equations of MAE and MAPE illustrate in Equation (11) and Equation (12) (Stellwagen, 2020) and figure 4.32 shows the relationship between actual and predicted values in the validation dataset.

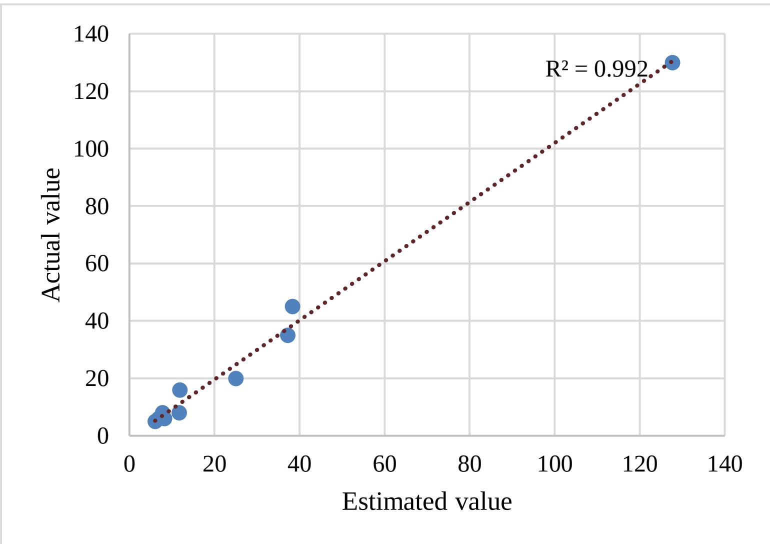

Figure 4.32: Relationship between actual and estimated values (parking demand)

4.5 Summary of Chapter

Data analysis was conducted in two approaches. The first stage was survey data analysis to identify the adequacy of parking provisions based on the trip generation pattern. The second stage was to develop a methodology to estimate the parking requirement. To achieve this, novel criteria should have to be identified. Therefore, to identify the criteria, opinion survey was conducted and using the AHP technique the criteria were ranked. Accordingly, floor area, employees, service population and parking capacity were selected for both parking demand and daily vehicle trip generation.

Survey data analysis identified different types of parking terms, trip generation patterns, modal share, trip purposes, distribution of variables and correlation coefficients. Then four regression models were developed based on the ownership of the building. Due to several limitations these four models were rejected and again the analysis was conducted. Afterwards, two models were developed for estimate daily vehicle trip generation and parking demand. For the development of daily vehicle trip generation model floor area, employees, service population and parking capacity have been entered as independent variables. Formerly using SPSS, multiple linear regression analysis, the final model was developed with the independent variables, employees, parking capacity and service population. The model had obtained 0.98 R^2 value. Similarly, for development of parking demand model, Floor area, Employees, Service population have been entered as independent variables and the final model was developed with the independent variables, Floor area and Employees. The model had obtained 0.92 R^2 value.

Finally, to validate the model results, data validation was done for each model with the 10 samples of data from Sri Jayawardhanpura Kotte municipal council area. To check the validity of MAE, MAPE was calculated. Daily vehicle trip generation model has obtained 1.94 MAE and 19.94% MAPE with a good forecast level and the parking demand model has obtained 1.67 MAE and 16.67% MAPE also with a good forecast level.

5 CONCLUSION AND RECOMMENDATION

This study is a new approach, to evaluate criteria for determining parking requirements in development projects of urban areas. The scope of the research is specifically focused on urban office development. Due to lack of standard regulations or a model to calculate vehicle trip generation and parking demand it was hard to forecast actual future figures. The trip generation is directly affected for parking demand in a particular area. While studying the parking of offices, this study has identified, there is a necessity to calculate trip generation patterns too. But the thing is, there is no standard method for that. UDA regulations are using to estimate parking demand or parking requirement. But there is a mismatch between regulated parking requirements and actual parking allocation since the regulations are formulated by considering the "Floor area" of the building with 1 for 150 sqm parking requirement for office development which was lastly amended in the CCDP 2008. Therefore, based on that scenario this research study was conducted.

Based on the identification of the research gap, three main objectives were formulated.

1. Evaluate the adequacy of parking provisions based on the trip generation patterns for urban office developments.
2. To identify and evaluate new parking estimation criteria based on literature analysis and opinion survey.
3. Develop the methodology to estimate parking requirements for urban office developments.

To achieve each objective, different types of methods were used. In order to identify the adequacy of parking provisions, In and Out surveys were conducted in 70 office buildings comprising of 35 governments, 21 private and 14 Semi government offices within the CMC area boundary. The study has identified trip generation patterns, different parking terms, utilization rates of parking (parking index), etc., in all 70 buildings.

New parking estimation criteria were identified through literature and opinion surveys. 30 expert personnel were taken for the sample. Based on the nominations five factors were selected for parking as well as vehicle trip generation. Then these nominated factors were ranked using the AHP technique. Individual consistencies and the final consistency values were estimated on the pairwise comparisons. Accordingly, it has proven floor area, employees, service population and parking capacity have a significant influence on parking estimation and daily vehicle trip generation.

Subsequently, the research developed four models to estimate vehicle trip generation and parking demand for government + semi-government offices and private office developments. Multiple Linear Regression analysis was used to develop the models. This classification was based on the ownership of the building. But there were identified limitations and less effectiveness of the developed four models.

Then by ignoring the classifications, the total sample was used to developed regression model for any types of office developments. Ultimately, two regression models were developed to estimate parking demand and vehicle trip generation of urban office developments.

In accordance to the estimations, floor area and employees were taken as the most influencing factors for parking demand. The developed model is shown in equation (21).

*Parking demand= 5.438+(0.003*Floor area) + (0.035* Employees)* (21)

The developed model has been earned a 0.92 R^2 value as well as a 1.94 DW value.

The daily vehicle trip generation model was formulated using MLRA for any office development as well. It has been used four independent variables which affected trip generation namely floor area, parking capacity, employees and the service population. Hence, regression analysis selected employees, service population and parking capacity as most influencing parameters for the dependent variable “daily vehicle trip generation”, it has excluded floor area due to the insignificancy. This vehicle trip generation model can be used to estimate vehicle trip rates both In and Out of urban office developments. The developed model is shown in Equation (20).

*Daily vehicle trip generation= 0.511+(0.074*Employees) + (0.251*Service population) +(1.134*Parking capacity)* (20)

The developed model earned 0.98 R^2 value and 2.07 DW value.

These models are applicable for model parameter limits as explained in section 4.3.

The developed two regression models included floor area, employees, service population and parking capacity as independent variables. The developed models can be used for new developments, and the developer has to estimate the number of employees, number of service population and parking capacity while in the design stage. Service population for a building is typically considered in its design of services such as lift capacity, lobby area, utilities, water/electricity demand, etc. Therefore, such estimates can be used for this.

Also, while working in the interior design process and the space planning of new development, the space planners and designers should have an overall idea about the functional factors (operations and activities of the organization, Accurate definition of user requirements, Space adjacency requirements, Specification of common facilities– Areas, Anticipation of change in the organization), technical factors (facility's physical constraints, Specification of ergonomic products, Provisions for the disabled, Adherence to life safety mandates, Analysis of telecommunication requirements, Analysis of potential demands generated by equipment on the facility) and financial factors of the development. (Hassanain, 2010).

One of the limitations of these models was some office buildings selected are not direct service providers for the customers. Therefore, there was a lesser number of service population except for other office buildings.

Finally, to check the validity of the developed models, model validation has been conducted. The validation data set was collected from the Sri Jayawardhanapura Kotte Municipal Council area. 10 numbers of data were collected for the validation. Then individual model validation was conducted. The mean absolute error (MAE) and the mean absolute percentage error (MAPE) were calculated to check the validity. Both models have obtained a "good forecast level" (10%< MAPE ≤ 20%). The daily vehicle trip generation model obtained 1.94 MAE and 19.9% MAPE value. The parking demand model obtained 1.67 MAE and 16.75% MAPE value proving a good forecasting level.

5.1 Recommendations

Based on the research findings, the following recommendations were developed for addressing each and every research objective.

The first objective is, Evaluate the adequacy of parking provisions based on the trip generation patterns for urban office developments. The present parking allocation methods are obsolete and not effective. Therefore, it is recommended that a new method is needed with a wide range of criteria.

Second objective is, To identify and evaluate new parking estimation criteria based on literature analysis and opinion surveys. To address the objective, it is recommended that novel criteria can be used to determine parking requirements for urban office developments. Selected criteria for parking demand are Floor area, Employees and Service population. However, the regression model selected Floor area and Employees as most significant criteria. Similarly, it is recommended that novel criteria can be used to determine daily vehicle trip generation for urban office developments. For that identified criteria are Floor area, Employees, Service population, Parking capacity. Ultimately the regression model selected Employees, Service population and Parking capacity as most significant criteria.

The third objective is, Develop the methodology to estimate parking requirements for urban office developments. To address that parking requirements/demand model was developed and it is recommended that it can be used to estimate parking requirement/ demand specifically for urban office developments. The developed model is mentioned in equation 21.

$$\textit{Parking demand} = 5.438 + (0.003 * \textit{Floor area}) + (0.035 * \textit{Employees}) \quad (21)$$

As well, daily vehicle trip generation model was developed and it is recommended that it can be used to estimate daily vehicle trip generation specifically for urban office developments. The regression equation is mentioned in equation 20.

$$\textit{Daily vehicle trip generation} = 0.511 + (0.074 * \textit{Employees}) + (0.251 * \textit{Service population}) + (1.134 * \textit{Parking capacity}) \quad (20)$$

6 REFERENCES

A.M.Fillone, & Tecson, M. (2003). Trip attraction of mixed-use development in metropolitan manila. *Proceedings of the Eastern asia Society for Transport Studies*, (pp. 860-868). Manila.

Aderamo, A. J., & Salau , K. (2013). Parking patterns and problems in developing countries: A case from Ilorin, Nigeria. *African Journal of Engineering Research*, 40-48.

Ajeng, C., & Gim, T.-H. T. (2018). Analyzing on-Street Parking Duration and Demand in a Metropolitan City of a Developing Country: A Case Study of Yogyakarta City, Indonesia. *Sustainability*, 1-14.

Al-Masaeid, H. R., & Fayyad, S. S. (2018). Estimation of Trip Generation Rates for Residential Areas in Jordan. *Jordan Journal of Civil Engineering, 12*, 162-172.

Al-Sahili, K., Abu-Eisheh, S., & Kobari, F. (2018). Estimation of New Development Trip Impacts through Trip Generation Rates for Major Land Uses in Palestine. *Jordan Journal of Civil Engineering*, 669-682.

Alvin Tx. (2019, June 27). Retrieved from municode: https://library.municode.com/tx/alvin/codes/code_of_ordinances?nodeId=PTIICOOR_CH5BU_S5-9OREPALORE

Austingtexas gov. (2018, Febuary 07). Retrieved from municode: https://library.municode.com/tx/austin/codes/transportation_criteria_manual?nodeId=TRCRMA_S9PA_9.7.0CAPARE

Bai, H., Liu, X.-x., Zhao, Y.-d., & Song, C.-h. (2011). Parking Demand Forecasting Model Based on Principal Component Analysis and BP Neural Network. *11th International Conference of Chinese Transportation Professionals (ICCTP)*, (pp. 372-379). Nanjing.

Building Services & Code Enforcement. (2012). *Building Services & Code Enforcement.* Salt Lake City.

Cambridge Dictionary. (2020). Retrieved from Cambridge University Press: https://dictionary.cambridge.org/dictionary/english/parking

Chakrabarti, S., & Mazumder, T. (2010). Behavioral Characteristics of Car Parking Demand: A Case Study of Kolkata. *Journal of Institute of town Planners* , 1-11.

Chang, J. S., Jung, D., Kim, J., & Kang, T. (2014). Comparative analysis of trip generation models: results using home-based work trips in the Seoul metropolitan area. *The International Journal of Transportation Research* , 78-88.

Chen, R. J., Bloomfield, P., & Fu, J. S. (2003). An Evaluation of Alternative Forecasting Methods to Recreation Visitation. *Journal of Leisure Research*, 441-454.

Chrest, A., Smith, S. M., Bhuyan, S., Monahan, D. R., & Iqbal, M. (2001). *Parking Structures: Planning, Design, Construction, Maintenance & Repair.* New York.

City of Colombo Development Plan (Amendment). (2008). *City of Colombo Development Plan (Amendment).* Battramulla: Urban Development Authority.

City of Fountain Valley California. (n.d.). Retrieved from CivicPlus: http://qcode.us/codes/fountainvalley/view.php?topic=21-21_22-21_22_040&frames=on

City of Houston. (2020, April 6). Retrieved from municode: https://www.houstontx.gov/planning/DevelopRegs/docs_pdfs/parking_req.pdf

Colombo Commercial City Development Plan 2019 – 2030. (2019). *Colombo Commercial City Development Plan 2019 – 2030.* Battaramulla: Urban Development Authority.

Colombo Municipal Council. (2019). Retrieved from www.soslc.lk: https://soslc.lk/en/cities/colombo-municipal-council#

CoMTrans. (2014). *Urban Transport System Development Project for Colombo Metropolitan Region and Sububs.* Colombo: Ministry of Transport.

CoMTrans. (2014). *Urban Transport System Development Project for Colombo Metropolitan Region and Suburbs, Technical Report 3: Characteristics of Present Transport Demand.* Colombo: Ministry of Transport.

Das, D., Ahmed, M., & Sen, S. (2016). On-street parking demand estimation model: a case study of Kolkata. *12th Transportation Planning and Implementation Methodologies for Developing Countries.* Mumbai.

Delaware Valley Regional Planning Commission. (1990). *Trip Generation from Suburban Office Buildings in Pennsylvania.* Pennsylvania: Delaware Valley Regional Planning Commission.

Department of Building & Safety. (n.d.). *Summary of Parking Regulations.* Los Angeles: Zoning Section - Department of Building & Safety (LADBS).

DKS Associates, T. S. (2006). *Central City Parking Master Plan.* City of Sacramento: Department of Transportation.

Dodeen, A. M. (2014). *Developing Trip Generation Models Utilizing Linear Regression Analysis: Jericho City asaCase Study.* Jericho City: An-Najah National University .

Engel-Yan, J., Hollingworth, B., & Anderson, S. (2007). Will Reducing Parking Standards Lead to Reductions in Parking Supply? Results of Extensive Commercial Parking Survey in Toronto, Canada. *Journal of the Transportation Research Board*, 102-110.

Engstrom, E. (1996). *Parking Regulation and Land Use in the Portland Metropolitan Region: A Case for Local Parking Districts and Shared Parking Arrangements.* Portland: Portland State University.

George, P., Kattor, G. J., & Malik, K. A. (2013). Prediction of trip attraction based on commercial land use characterisics. *International Conference on Energy and Environment (ICEE 2013)*, (pp. 352-359). Kottayam, Kerala, India.

Ghuzlan, K. A., Al-Omari, Bashar , H., Khasawneh, & Mohammad A. (2016). Parking Demand for Residential Apartment Buildings in Jordan. *ITE Journal*, 32-36.

Gunasoma, H. D. (2018). *A model development for prioritization and optimization of pavement maintenance for provincial road networks.* Katubedda, Moratuwa: University of Moratuwa.

Hassanain, M. A. (2010). Analysis of factors influencing office workplace planning and design in corporate facilities. *Journal of Building Appraisal*, 183–197.

Hensher, D. A., & King, J. (2001). Parking demand and responsiveness to supply, pricing and location in the Sydney central business district. *Transportation Research Part A* , 177-196.

ITE Trip Generation Manual. (2010). *Trip Generation Rates from the 8th Edition ITE Trip Generation Report.* Florida: Florida Department of Transportation.

Jayasinghe, A., Sano, K., & Nishiuchi, H. (2015). Explanning traffic flow patterns using centrality measures. *International journal for traffic and transport engineering*, 134-149.

Jittrapirom, P. (2010). Sustainable Transport System and Parking Organisation: A case study of Bangkok´s Parking Standard. *ATRANS RESEARCH* (pp. 52-59). Bangkok: https://www.researchgate.net/publication/312652202.

Ko, J. (2013). Vehicle Trip Generation Rates for Office Buildings under Urban Settings. *ITE journal*, 41-45.

Kuah, G. K. (1991). Estimating Parking Demand for Mixed-Use Developments Subject to TSM Ordinances. *ITE Journal*, 19-24.

L.R.Kadiyali. (2007). *Traffic Engineeriing and Transport Planning.* New Delhi: Romesh Chander Khanna.

Lau, W. W., Poon, P. S., Tong, C. O., & Wong, S. C. (2005). The Hong Kong second parking demand study. *Transport* (pp. 53-59). Hong Kong: Proceedings of the Institution of Civil Engineers.

Lee, Y. W. (2014). Study on Establishment of On-Street Parking Demand Model According to Total Building Floor Area. *Architecture and Civil Engineering 2014*, (pp. 26-29). Dong-gu.

Lim, H., Williams, G. T., & Abdelqader, D. (2017). Alternative approach for forecasting parking volumes. *Transportation Research Procedia*, 4171-4184.

Litman, T. (2016). *Parking Management : Strategies, Evaluation and Planning.* 1250 Rudlin Street, Victoria, CANADA: Victoria Transport Policy Institute.

Macababbad, M., Regidor, F., & Bartolome, D. S. (2009). A Study on the Local Trip Generation Characteristics of Government Office Land Use. *Proceedings of the Eastern Asia Society for Transportation Studies.* Philippines.

Macababbad, R. J., Regidor, J. R., & Bartolome, D. S. (2009). A Study on the Local Trip Generation Characteristics of Government Office Land Use. *Proceedings of the Eastern Asia Society for Transportation Studies.* Philippines.

Manchanda, M., & Panda, U. (2007). *Spatial Trip Pattern of Rourkela.* Rourkela: National Institute of Technology .

Mathew, T. V. (2014). *Transportation Systems Engineering- Parking studies.* Bombay.

Mathew, T., & Rao, K. V. (2007). Introduction to Transportation Engineering. *NPTEL*, 38.1-38.10.

McCahill, C., Garrick, N., & Atkinson-Palombo, C. (2014). Visualizing Urban Parking Supply Ratios. *Congress for the New Urbanism 22nd Annual Meeting*, (pp. 1-8). Buffalo, New York.

Missoula. (2020, March 3). Retrieved from municode: https://library.municode.com/mt/missoula/codes/code_of_ordinances?nodeId=TIT20ZO_CH20.60PAAC

Mohamed, S. S., & Hokao, K. (2000). *Estimation of Generated Traffic by New Developments: Current Practice And Possible Improvements Based On Bangkok Experience.* Canada: Victoria Transport Policy Institute.

Mousavi, A., Bunker, J., & Lee , B. (2012). A New Approach for Trip Generation Estimation for use in Traffic Impact Assessment. *Proceedings of the 25th Australian Road Research Board Conference* (pp. 1-15). Brisbane: Australian Road Research Board (ARRB).

Naydenov, N. (2010). Parking Survey - Methodology and Case Study. *FIG Congress 2010* (pp. 1-14). Sydney: ResearchGate.

Pappas, V. (2013). *Data classification methods in GIS.* University of Thessaly.

Parking and Loading, D. S., & City of St. Petersburg City Code. (n.d.). *Parking and Loading, Design Standards ; City of St. Petersburg City Code.* St. Petersburg: City of St. Petersburg.

Parking Standards and Traffic Impact Assessment. (2016). *Parking Standards and Traffic Impact Assessment.* St Peter Port.

Parking Utilization Analysis. (2017). *Parking Utilization Analysis.* City of Annapolis: Municipal Services.

Parmar, J., Das, P., & Dave, S. M. (2019). Study on demand and characteristics of parking system in urban areas: A review. *Journal of Traffic and Transportation Engineering*, 111-124.

Patel, V., Kedia, A., & Ravindran, S. (2016, June 6). Retrieved from www.researchgate.net: https://www.researchgate.net/post/What_affect_the_trip_generation

Plnr.Jayasundara, D. (2019, 04 11). Development Plans and Parking regulations. (M. Priyadarshani, Interviewer)

Puckett, E. M. (2013). *Parking Strategies for Suburban Mixed-Used Developments.* Blacksburg, Virginia: Faculty of the Virginia Polytechnic Institute .

R.J.C.Chen, Bloomefield, P., & Fu, J. S. (2003). An evaluation of alternative forecasting methods to recreation visitation. *Journal of leisure research*, 441-454.

R.P.Roess, Prassas, E. S., & McShane, W. R. (2011). *Traffic Engineering-Fourth Edition.* New York: Pearson Higher Education.

Rahman, R., Kuhu, N. N., Shakil, S. H., & Quadir, K. B. (2011). *Parking demand and supply analysis of different commercial land uses along Mirpur Road.* Bangladesh: Bangladesh University of Engineering and Technology.

Ramli, I., Hassan, S., & Hainin, M. R. (2017). Parking demand analysis of rest and service area along expressway in southern region, Johor Malaysia. *Malaysian Journal of Civil Engineering*, 108-118.

Regidor, J. (2006). A review of trip and parking generation rates in the Philippines. *Philippine Engineering Journal*, 1-12.

Regidor, J. R. (2007). Study on the trip generation characteristics of business process outsourcing (BPO) companies in th Philippines. *Journal of the Asia Social for Transport Studies*, 846-852.

Reid, F. (1982). Critique of the ITE Trip Generation Rates and an Alternative Basis for Estimating New Area Traffic. *Transportation Research Record*, 1-5.

Sandaruwan, A., Karunarathne, T., Edirisinghe, J., & Wickramasinghe, V. (2019). Carpooling: A Step to Reduce Traffic Congestion in Sri Lanka. ResearchGate.

Schneider, R. J., Shafizadeh, K., & Handy, S. (2015). Method to adjust Institute of Transportation Engineers vehicle trip-generation estimates in smart-growth areas. *THE JOURNAL OF TRANSPORT AND LAND USE*, 69-83.

Shen, Q. (1997). Urban transportation in Shanghai, china: problems and planing implications. *International Journal of Urban and Regional Research* , 589-606.

Stellwagen, E. (2020). *A guide to forecast error measurement statistics and how to use them*. Retrieved from Forecast pro.com: https://www.forecastpro.com/Trends/forecasting101August2011.html

Tiexin, C., Miaomiao, T., & Ze, M. (2012). The Model of Parking Demand Forecast for the Urban CCD. *2012 International Conference on Future Energy, Environment, and Materials* (pp. 1393-1400). Tianjin, China: Energy Procedia.

Toledo, T., & Bekhor, S. (2012). Framework and Model for Parking Decisions. *Journal of the Transportation Research Board*, 30-38.

Trip generation and parking rates manual Emirate of Abu Dhabi. (2012). *Trip generation and parking rates manual Emirate of Abu Dhabi.* Abu Dhabi, United Arab Emirates: Department of Transport.

United Nations. (2014). *World urbanization prospects:2014.* United Nations, Department of Economics and Social Affairs.

Waloejo, B. S., Surjono, & Sulistio, H. (2012). The influence of trip attraction on the road’s level of service(LOS) at traditional market land use. *Journal of Applied Environmental and Biological Sciences*, 92-96.

Waris, M., Panigrahi, S., Mengal, A., Soomro, M. I., & Mirjat, N. H. (2019). An Application of Analytic Hierarchy Process (AHP) for Sustainable Procurement of Construction Equipment: Multicriteria-Based Decision Framework for Malaysia. *Mathematical Problems in Engineering*, 1-20.

Weerasekera, K. S. (2011). Impact on Existing Transport Systems by Generated Traffic due to New Developments. *ENGINEER*, 31-37.

Wong, S. C., Tong, C. O., Lam, W. C., & Fung, R. Y. (2000). Development of Parking Demand Models in Hong Kong. *Journal of Urban Planning and Development*, 55-74.

Wu, Z., & Fan, Y. (2011). Model of the Parking Demand Prediction for Urban Complex. *11th International Conference of Chinese Transportation Professionals*, (pp. 519-526). Nanjing.

Zu, Z., Jin, Z., & Zhao, Y. (2014). Exploration of the parking problems in Wujiang District. *CICTP 2014: Safe, Smart, and Sustainable Multimodal Transportation Systems* (pp. 1945-1952). China: ASCE .

APPENDIX A: Questionnaire form

1. Are you satisfied with the current parking regulations?

	1	2	3	4	5	
Needs improvements	○	○	○	○	○	Satisfied

2. What are the commoly used parking demand calculation methods in Sri Lanka?

3. What is your perception about current parking demand calculation methos in Sri Lanaka?

4. Floor area is considered as a major factor in determining the parking demand. What is your perception on its suitability?

	1	2	3	4	5	
Least suitable	○	○	○	○	○	Most suitable

5. What are the exiting Trip Generation calculation models used in Sri Lanka?

6. What methods are used to calculate the trip generation rate specifically for an office building?

7. What factors should be considered when calculating the parking requirement for an office building?

8. What factors should be considered when calculating the trip generation rate for an office building?

9. What is your perception about the current parking regulations in Sri Lanka?

10. If needed, what revisions would you suggest?

11. Do you have any suggestions to improve existing parking regulations for an office building?