Addis Ababa University
Addis Ababa Institute of Technology
School of Mechanical and Industrial Engineering

Analyzing and Optimization of Car Parking Space for Addis Ababa City

Case of ADDIS KETEMA sub-city

By

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A Thesis Submitted to School of Graduate Studies of Addis Ababa University in Partial Fulfillment for the Award of the Degree of Masters of Science in Mechanical Engineering (Industrial Engineering Stream).

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This is to certify that the thesis prepared by **Mengistu Manaye,** entitled: **Analyzing and Optimization of Car Parking Space for Addis Ababa city** submitted in partial fulfillments of the requirements for the degree of Master of Science (Mechanical and Industrial Engineering) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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I hereby declare that the work which is being presented in this thesis entitled, "**ANALYSIS AND OPTIMIZATION OF PARKING SPACE FOR ADDIS ABABA CITY**" is original work of my own, has not been presented for a degree of any other university and all the resource of materials used for this thesis have been properly acknowledged.

By

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Abstract

Currently in Addis Ababa there are so many problems which are mainly concerned with shortage of parking space such as congestion of roads due to imbalance between on-street parking capacity and number of vehicle, emission of CO_2 to the environment due to searching of parking space and idle of the drivers by waiting parking spot. The Parking problems have been analyzed with the consideration of both quantitative and qualitative data collection methods. Different data collection methods has been used in this study, such as structured and semi-structured questionnaires, interviews, and observation and survey data collection methods are applied and then the collected data are analyzed and presented by Excel and Minitab. The study has analyzed the current parking system and finding of optimal parking location by considering parking site selection criteria and using AHP method. The space optimization model considers different constraints such as average arrival rate, parking capacity, vehicle size, parking angle and average parking duration and formulate LP model and LINGO17 software has been used to solve the LP model. In addition this study considers two scenarios which are average daily arrival rate of vehicles and parking duration and average daily maximum arrival rate of vehicles and average parking duration in the parking lot are inputs to develop space optimization linear programming model. As a result, it has found that existing parking capacity is increased by 119, 328, 421, and 483 parking spot from 60 parking spot and scenario- one fulfilled with 45, 60, and 90 degree of parking angles. And when considered scenario-two the existing parking capacity is increased by 11.2%, 31%, 40% and 45.4% of parking capacity of vehicles with respective parking angle. Finally comparing the result with actual parking capacity of on-street parking capacity with improved LP model and saved parking area are 6040 meter squares from 90 degree parking angle, 1492.48meters square from 30 degree parking angle, 4102.06meter square from 45 degree parking and 5268.08 meter square from 60 degree parking angle. Therefore, maximum saved parking area is 6040 meter square from 90degree parking angle. But the recommended parking angles for on-street parking are 30, 45, and 60 respectively.

***Keywords**: parking space optimization, AHP method, linear programming*

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CHAPTER-ONE

1.1 Background and Justification of the Study

The civilization and industrialization of the world create migration of the population from rural areas to urban areas that cause concentration of population in cities. The result of civilization changes living standard of people from, cave to house, rural area to urban area, and from animal transportation to car transportation. The car needs the space at the end of their destination that called parking area. The slowdown development and mismanagement of the available parking space creates parking problem in the cities (Sofiene Abidi et al, 2015).

Concerning to the parking issues, the main social problem is arisen from the drivers who have been searching the parks spot in the cities .There are some Statistics data which illustrate the challenges of parking space as if which couldn't be unbelievable right now. For instance the drivers of United Kingdom will spend their time about 2,549 hours for searching a parking spot over their lifetime in average. In addition this the other survey data estimated show that 95% of British people added an extra-long distance trip for searching a parking spot. Such statistics have been observed elsewhere and are not just in the UK only. Currently, the demand of parking space has been increased from time to time in the cities. For example, there is a report which shows recently that, over one year in a small Los Angeles business district, vehicles searching for parking burned 47,000 gallons of gasoline and produced 730 tons of carbon dioxide (Nicole Taheri et al, 2015).In addition, there is also a report that shows the demand of parking space is going to be increased day to day in Netherlands like UK and USA parking space as a result the average vehicles parking time is 95% of their travel time of vehicles .So it is an indicator of the Netherlands government to boost or constructs new parking facilities or locations for Meeting the needs of parking which has to be used as the parking space for consumers in the city (Hidde, 2015).

The rapid development of vehicles and motorcycle traffic in Asian countries is a unique phenomenon. During late 1980s-early 2000s, motorcycle population exponentially grew in Asian countries, for instance, in China, Vietnam, India and Indonesia and Thailand 25%, 15%, 11% and 9% per year respectively. As a result, Asian cities experienced rapidly increasing parking

space need to park their motorcycle. The Motorcycle populations grew deteriorating the parking system since the available space on the roads has remained unchanged and created congestion of roads, drivers search parking lot for long time and constructions of public parking lot has developed slowly and cannot match with the demand in the Asian as the result many illegal parking and illegal parking fees collected from those cities (Friedrich, 2016).

Lack of public parking is the major parking problem in Africa and this can be easily observed in major cities. Due to undergoing of rapid motorization and urbanization, this problem has been observed mainly in many municipal governments in Africa. Pertaining to transportation, Parking is one of the comprehensive components in land use appearing in residential, shopping and industrial areas, and is related to all kinds of trips occurring in traveling, shopping and leisure trips. According Step & Mint parking survey estimates most cities in Africa could lack up to one million parking spots in 2020G.C.

Like most African cities, Addis Ababa, has been experiencing huge population and Urbanization increase. The population of Addis Ababa is about 3.1 million and is expected to increase by 2.1% every year (Central Statistical Agency, 2010).Due to the dynamic change and the life style of the city dwellers people prefer to travel by vehicles from place to place by Car in Addis Ababa city. Every time, In order to travel from place to place of the major facilities and public services, like the market area, the schools, the religious centers, offices and the like, are concentrated in the city center. This demand has led to the development of transportation but adversely affect the effective uses of road due to lack of parking space in Addis Ababa (Shiferaw, 2014).

1.2 Justification of the study

In the study reports, annual registered cars parking land demand is bigger than 310 football fields in Delhi, In Lagos the car parking demand of the existing car is equivalent to 115 football fields and in Addis Ababa the registered car parking land demand of the existing car is equivalent to 110 football fields. So that land is expensive and can be used for other social and public needs in Addis Ababa (GIZ).

In this research, the long waiting time of parking spot, long distance travel to search parking spot, congestion on the road and long walking distance are analyzed and optimization of parking space by developing parking space optimization models to improve parking service in Addis Ababa.

1.3 Statement of the Problem

Addis Ababa is a fast growing city in the urbanization and transportation sectors .It is also a seat for more than 100 embassies for different countries. In addition, it accommodates many international Aid and Development organization. Due to Fast growing of the city is the result of exhibiting high social, economic, structural and change in the city. There are about more than 800,000 vehicles found in Ethiopia (H.Mariam, 2017) and among them, 70% of registered vehicles are found in Addis Ababa (Transport, 2011). Due to the increments of those sectors in the city, Parking facilities is going to become the basic issue, So getting parking facilities simply is the highest problem and difficult which leads the drivers spend more time for searching the vacant parking spots as it is shown in reality situation (Chaniotakis, 2014).

As study estimation shows that 14% of traffic density is created by searching for parking space and 50% of increase in congestion-related time loss on roads has been generated due to shortage of parking space (Brooke, 2015).The problem of traffic congestion in urban cities has been one of the very major stressing issues and one-third of this traffic congestion in the world is created by cars searching for parking spot due to the unbalancing of the parking demand and the availability of the space (Joseph Y.J et al, 2015). In this case the drivers to arrive a destination people may need to start their trip before their scheduled program and will be forced to spend more time on the roads. In addition, it has economic impact on the country and the government expending more money to adjusting this congestion problem due to shortage of parking space. For instance, in USA studies show that in the case of traffic congestion the government losing up to 48 billion US dollars in 1990 and in this time the government losing up to 124 billion US dollar (USD) per year with an expectation of rising the cost up to 186 billion USD in 2030 (Serugendo et al , 2017).

In Addis Ababa in on-street parking service, due to shortage of parking facilities the drivers' searching parking lot for long time and vehicles are consuming more fuel and emitting high amount of CO_2 to the environment, due to parking space shortage average traffic speed in Addis Ababa is about 10km per hour in peak hour (GIZ) , inefficient parking space management due to that vehicles blocked the roads ,idle the drivers by waiting the parking spot, illegal parking on the roads and that creates congestion on the roads. In addition, On-street parking service it does not have standardized time interval to park their car in parking lot

and departure time and cars without parking lots are parked on roads or in residential area, which makes congestions of the road, even blocked passageways of ambulance in the city.

So that this study is done for parking analysis and optimization of car parking space by developing Mathematical model and finding of optimal parking location to improve the parking service of Addis Ababa city.

1.3 Objectives of the Study

1.3.1 General objectives

The general objective of this research is to analyze the current car parking system of Addis Ababa and optimize of parking space by developing the space optimization Mathematical model to improve parking service.

1.3.2 Specific Objective

To attain the general objective the following specific objectives have been identified for its achievement. These are to:-

- Deeply review the current parking strategy and policies of Addis Ababa city.
- Study and analyze the existing car parking system activities, parking site selection criteria and parking problem in selected area in Addis Ababa.
- Measuring the effects of parking lot shortage on transportation system in Addis Ababa.
- Develop space optimization model to improve car parking service and to increase parking space and parking capacity.
- Finally provide appropriate conclusions and recommendations to car parking service for Addis Ababa.

1.4 Research Questions

This research is intended to answer the following research questions:

1. What kind of car parking strategy and policy existing in the Addis Ababa city?
2. What are the characteristics of the current car parking service system of Addis Ababa city?
3. What kinds of space optimization models applied to increase parking space and capacity?

1.5 Significance of the Study

The result of this paper is contribute to the body of knowledge in car parking system and to identifies literature gaps to be considered in future research works. A car parking system analyzed and developed good solution for parking system problems to provide insights to revise parking police and establish car parking strategic directions on the master plan and provide information about consideration factors for parking site selection criteria for Addis Ababa city. This study contributes to the city and drivers economically by reducing traffic congestion on the roads, searching time, and waiting time.

1.6 Scope of the study

The scope of this research is to analyze current parking system and formulation of model to optimize parking space with help of LP model to increase parking capacity of Addis Ketema sub-city and selection of optimal parking site by considering parking site selection criteria for Addis Ketema sub-city by using AHP methods. Therefore, the scope of the research is limited to specific parking locations and expected to provide the general idea to have convenient public, private parking lots and traffic management police in Ethiopia particularly in Addis Ababa.

1.7 Limitation of the study

The study was targeted only Addis Ketema sub-city based on the selection criteria of parking location by Experts as well Engineers comparison decision and model formulation which consider one way direction and road diameter greater than 20 meters roads only. Additional limitation of the study is not considering bus station effects on the parking system of Addis Ketema sub-city.

1.8 Structure of Thesis

The research paper consists of the following chapters:-

1. Chapter-one: Introduction about parking system, statement of problem, justification of the study, objective of the paper, Basic research questions, signifies of research, and scope of research and limitation of study.
2. Chapter-two: introduced about parking system, parking strategy, parking problem solving methods and models are overviewed and deals from scientific literature focused on selected topic.
3. Chapter -three. Research Approach, sampling techniques, study area selection procures and methodology are well defined to carry out the research work.
4. Chapter-four. Study the existing parking system by using interviews and questionnaire to pick out the main challenging parking problems.
5. Chapter-five: Model formulation to optimize parking space and AHP Analysis by considering parking area selection criteria to select optimal parking location for Addis Ketema sub-city.
6. Chapter-six. Analysis and discussion of the result of Lingo software by considering different parking angles and scenarios.
7. Chapter-seven: Conclusions& Recommendations based on the result of study.

CHAPTER-TWO

2.1 Literature Review

2.1.1Introduction

In this chapters discussed about the general concept of parking, types of parking, side effect of parking, strategies and polices of parking, analysis parking design factors and optimization models of the parking problems in the literature are presented.

2.2 What is Car parking

Parking is an essential component in every car trip especially in the urban area context and plays major role in the transport system since all vehicles require a parking location when they are not being used. In many research Parking system has been studied regarding the following different factors which are mode of choice, location accessibility, and network performance due to congestion of traffic and parking location choices behaviors of drivers depend on the factors of access time to parking location, parking fees, walking distance to final destination and a number of socio-economic characteristics of the driver (Adam J. Pel et al, 2016).

It is defined as parking is service where some operators in the system and provide parking service for the customers such as motor vehicles, passenger cars and truck vehicles. The services were given based on an hourly, daily or monthly basis. The service areas are parking garages, parking stations and valet parking and Car parks operated by councils are excluded from this industry (Report, 2014).

2.3 Types of Parking

There are three main types of parking space classified such as parallel parking, public off-street parking and private and Non-residential parking.

1. **On-street parking**: On street parking means the vehicles are parked on the sides of the street itself. In addition, on-street parking as its name suggests, a parking space on the public road although this may become somewhere parked on the road, or the side of the road, is only semi-public. On-street parking often takes place, either legally or not, on space at the side of the road that is nominally reserved for pedestrians.

In On-street parking service is a common feature in most of the developed cities around the world. On-street parking assists to improve economic viability of commercial developments along transport corridors by providing easy and convenient access for customers, delivery vehicles and employees of such developments. However, the provision of on-street parking along transport corridors could adversely impact the capacity as well as the achievable driving speeds of the adjacent road. Road safety is another key factor which needs to be considered when considering the provision of on-street parking along a transport corridor. The debate regarding the merits and drawbacks of on-street parking stem from a lack of research surrounding the subject over the last two to three decades. The utilization of on-street parking is considered to be a more efficient use of land as it limits the need for off-street parking and access points to properties adjacent to major arterial roads. This aspect of on-street parking also reduces costs for the businesses, maximizes land utilization and creates a pedestrian friendly environment for the community by delineating vehicles and land use. Extending from this concept it is believed to improve pedestrian safety by providing a barrier between the flowing traffic and the footpath as well as reducing the speed of vehicles travelling on the roadway. Although there are a number of benefits in providing on-street parking, there are some adverse impacts, particularly on traffic flow. On-street parking can impact the road capacity in two ways. The reduction of the available lanes of a road to accommodate on-street parking is the primary factor that reduces road capacity. Additionally, on-street parking maneuvers can cause extensive delays, especially on heavily trafficked roads. This creates stop-start traffic flow behavior for the lanes adjacent to the parking lane, thus affecting the capacity of the road section (Wijayaratna, 2015).

Figure 1: On-street parking **(Rye, 2010)**

Parallel parking

The vehicles are parked along the length of the road. Here there is no backward movement involved while parking or imparking the vehicle. Hence, it is the safest parking from the accident perspective. However, it consumes the maximum curb length and therefore only a minimum number of vehicles can be parked for a given curb length. This method of parking produces least obstruction to the on-going traffic on the road since least road width is used. The length available to park (N) number of vehicles,

$$N = \frac{l}{5.9}$$

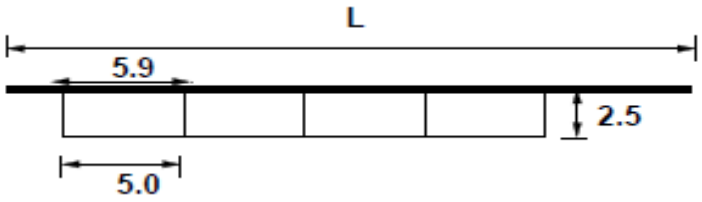


Figure 2: parallel parking type adapted **(Tom V. Mathew et al, 2014)**.

30°parking:

In the thirty degree parking the vehicles are parked at the 30° degree and parked at sides of the roads and saved maximum parking are compared with parallel parking

The general formula formulated as the following

$$AB = OB\sin 30^\circ = 1.25$$

$$BC = OP\cos 30^\circ = 4.33$$

$$BD = DQ\cos 60^\circ = 5$$

$$CD = BD - BC = 5 - 4.33 = 0.67$$

$$AB + BC = 1.25 + 4.33 = 5.58$$

N=Number of vehicles L = AC + (N-1) CE =5.58+ (N-1)5 =0.58+5N

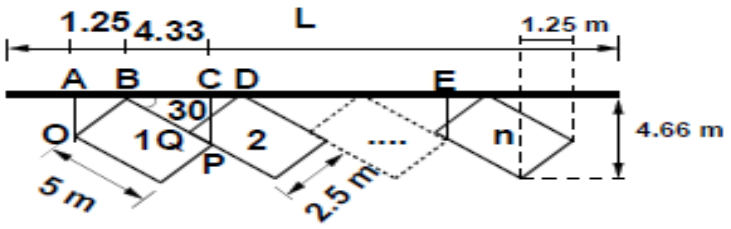


Figure 3:30°parking type **(Tom V. Mathew et al, 2014)**

45° parking

This parking angle saved and increases parking capacity more the parallel parking and thirty degree parking number of vehicles can be parked.

The general formula are Length of parking space available N=number of vehicles in a given area. L = 3.54 N+1.77

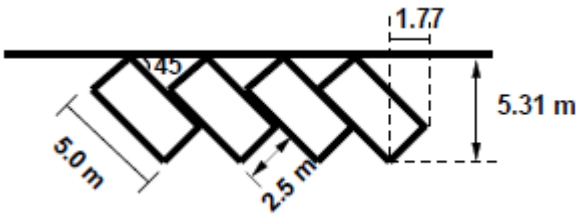


Figure 3:45◦ angle parking adapted **(Tom V. Mathew et al, 2014)**.

60° parking

This type of parking area accommodated more than the above parking types and it's recommended to the angle parking in the on-street roads.

The General formula are Length of roads =2.89N+2.16.

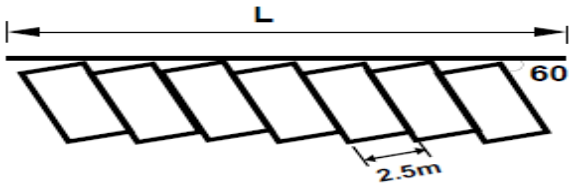


Figure 4:60° angle parking adapted **(Tom V. Mathew et al, 2014)**.

Right angle parking

The right angle parking, the vehicles are parked perpendicular to the direction of the road. This parking angle saved maximum road width and length that creates congestion on the roads by reducing road diameters. In this type of parking, the vehicles need complex maneuvering and this may create congestion and accidents. This arrangement causes obstruction to the road traffic particularly if the road width is less. The 90 degree angle parking is the most efficient in terms of layout and perception. Aisles are wide enough for two way traffic so it is easy to understand the lot design. Circulation is the most flexible and motorists do not need to worry about going the wrong direction down an aisle. However, many people are not comfortable with 90° parking and prefer angle parking.

The general formula are Length available for parking N number of vehicles is L = 2.5N

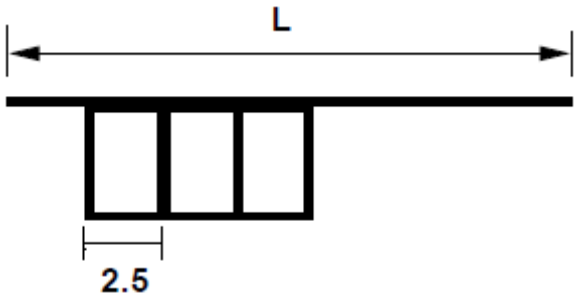


Figure 5:90° angle parking **(Tom V. Mathew et al, 2014)**

2. Public off-street

This type of car parking lot owned or operated by the private or public sectors and drivers park their car subject to complying with any regulation such as paying a free and maximum stay in hours. The vehicles parks are not on the public roads, in which any member of the public can park their car in this public off-street parking facility.

Private off-street parking

This is car parking that is associated with a particular building or land-use. For instance including parking for a shopping center, or an office building. Only people who are connected

with that building or land-use should, in the theory, be able to use the parking, and the land owner has control over this within relevant legal constrain.

2.4 Factors Affecting Parking Lot Design

Parking lot space is efficiently Utilized the result creates more parking capacity. In another hand, the shortage of the number of parking spaces created a challenge to utilize the parking areas more efficiently. Parking lots vary in design, size and location. The capacity of any parking lot depends on the number of vehicles it services, which is a function of the parking angle inside the parking lot. Main factors affect the design of parking lot such as:-

1. The number of vehicles that need to be accommodated.
2. The parking angle.
3. The circulation system within the parking lot and
4. The expected vehicle size.

When constructing any parking lot, the main objective is to provide the maximum capacity with a convenient and safe circulation. There are many problems associated parking such as:-

- Shortage of land in the city.
- Strategy and police problems
- Inefficiently usage of space.
- Management problem of the system.

The existing parking lots should be managed efficiently before building new parking facilities. The parking stalls can be designed with different angles such as 45°, 60°, and 90°. The angle of the parking stalls has a great impact on the capacity and the circulation of the parking lot. The 60°parking angle is the most common angle because of the easy entry and exit of vehicles from the parking facility. Also the 60° parking angle has a reasonable traffic lane width. The 90° parking angle provides a reasonable number of parking spaces for a given area. But due to the difficulty of entering and leaving the parking stall, it's only recommended for all-day parking such as university or work place parking garage (Akmal s el al, 2014).

2.5 Side Effect of parking

In case of parking they have some main problems on the traffic flow such as congestion of roads, environmental pollution, accidents in the road sides and obstruction to fire fighting operations process in the city.

1. **Road Congestion**: due to Parking in the on-street roads that creates congestion in the city and reducing the road capacity and width that creates congestion. Congestion reduced the speed of vehicles; the movement takes too much time, and waiting time increase. In addition of that, the vehicles operational cost and fuel consumption increases due to congestion and government loss economic development.
2. **Road side Accidents:** due to parking in the on-street parking the vehicles created accidents by carelessness maneuvering, carelessness opening of the doors and in the time of entering and existing from parking facilities.
3. **Environmental pollution**: In the parking activities vehicles sending some toxic gas into environment when car moving to search parking lot and creates high noise in the city of entering and existing time from parking locations. This pollution gases affects the aesthetic beauty of building and city.
4. **Obstruction of firefighting**: due to parking vehicles Parked on the street that blocked the movement road of emergence ambulance, sometime blocking the accessing way of the buildings and commercial areas, and movement of fire-fighting vehicle in the city.

2.6 Addis Ababa Parking Strategy

Transport Policy of Addis Ababa Transport Policy of Addis Ababa in 2011 shows that, parking is identified as one of the key "infrastructural “challenges. However, there is not enough off-street parking, and too much on-street parking according to the observed nature of problems identified in that document essentially. For example, lack of off-street parking facilities and over utilization of road space by parked vehicles" is high on the list of infrastructure issues under section 1.3 "Critical issues in the Transport Sector" of the aforementioned Transport Policy, "The issue of parking. The main concerns pertaining to parking can be analyzed as the overutilization of road space by parked vehicles, lack of off-street parking facilities, and the need to create and incentivize the use of park-and-ride facilities related to mass transit services is indeed an important area of concern for sustainable transport policy. However, infrastructure

is not the problem in this phenomenon rather it is better understood as a market failure. While there are instances when developers flout the law and do not provide the necessary off-street parking or illegally convert parking to other uses, the main issue is that parking in general is not appropriately recognized as a commodity and regulated as such. In reorienting parking policy along these lines, parking can be a useful tool to help shape streets as the building blocks in the city (Bank, 2014).

2.7 Parking and access management

As repeatedly mentioned in the above, parking is a critical component, as well as implementation tool, of the so called green growth of transport strategy, because parking policy has to do great efforts to changes of demand from time to time. The related concept of parking policy is the access management, which formulates the rules that public and private developers must aware of and keep in mind when providing access from private property and developments to the public street network. There are factors which affect the performance of the street network where and how access roads connect to it in terms of both their link and place making functions. For example, if the decision of management is not professionally done, it can reduce the basic performance of materials by introducing vehicular interference without regular plan and inappropriate points in the network. So In the case of both parking and access management, there should be appropriate enforcement that critical decision making about compliance or fulfillment should be made at the sub-city level which includes both the way to getting the strong actions are carried out and the decisions about giving permissions for construction. The objective of a parking management activity mainly focuses on confirming the parking assets both public and private are well developed and managed in a manner that gives benefits such that wise use of the private car consistent within the broader objectives of enhancing accessibility while minimizing vehicle distance of travel, as the same time the interference of car parking activities on both the link and place-arrangement functions of urban streets. Access management and parking will have the following benefit:-

- Having parking charges, improved access to available parking spaces by efficient space management.
- Sufficient availability of parking spaces that reduces the traffic congestion caused by vehicles searching.

- Enhancements of parking through improved system to reduce the street traffic congestion
- Parking will be as investment and city improvements by using parking revenues
- Improved traffic related problems and situations through suitable access controls concerned with land development
- Higher developer ideas of financial responsibility in delivering of traffic improvements concerned with their developments.

2.8 What is optimization?

Optimization is the study of decision problems in which seeks to maximizing (profit, capacity, efficiency) or minimize of loss (cost, fuel, material cost etc) a function by systematically choosing the values of variables within their allowed constraints (Zhang.G et al, 2015).

Optimization is also known as mathematical programming, finding optimal solutions that give maximum performance, profit, output or satisfaction and minimum cost, waste or dissatisfactions. It solves the problem of deciding how to optimally allocate scarce resources such as people, materials, spaces, money and land. An optimization model attempts to optimize an objective function by searching for the best set of decision variables that fulfill the given constraints. It is common to use the word" optimize", which means to maximize or minimize, in any optimization problem. A mathematical function, also known as an objective function, to be optimized could be a function of only one variable, called single-objective problem, or a function of multiple variables, called multi-objective problem. Furthermore, an objective function could also be constrained or unconstrained (J.P.F. Charpin et al).

Optimization is a process of making a system or decision as functional or effective as possible. Due to the significance of optimization, especially global optimization, its application is often used in daily life. A desire to achieve optimality is one of the most underlying precepts in the world today.

There are three essential components of an optimization model which are:

1. Decision Variables**:** The decision variables represent unknown values in the constraints. The contrast to problem data, which are values that are either given or can be simply calculated from what is given.

2. Objective function: every linear programming has objective .This is objective is to maximized or minimized decision variables.
3. Constraints**:** every linear programming has constraints to indicating limited resource in the production process or in service.

2.8.1 Optimization approaches

The optimization process helps decision-makers to determine realistic and practical outcomes to management complex problems. The process of optimization is shown in Figure.

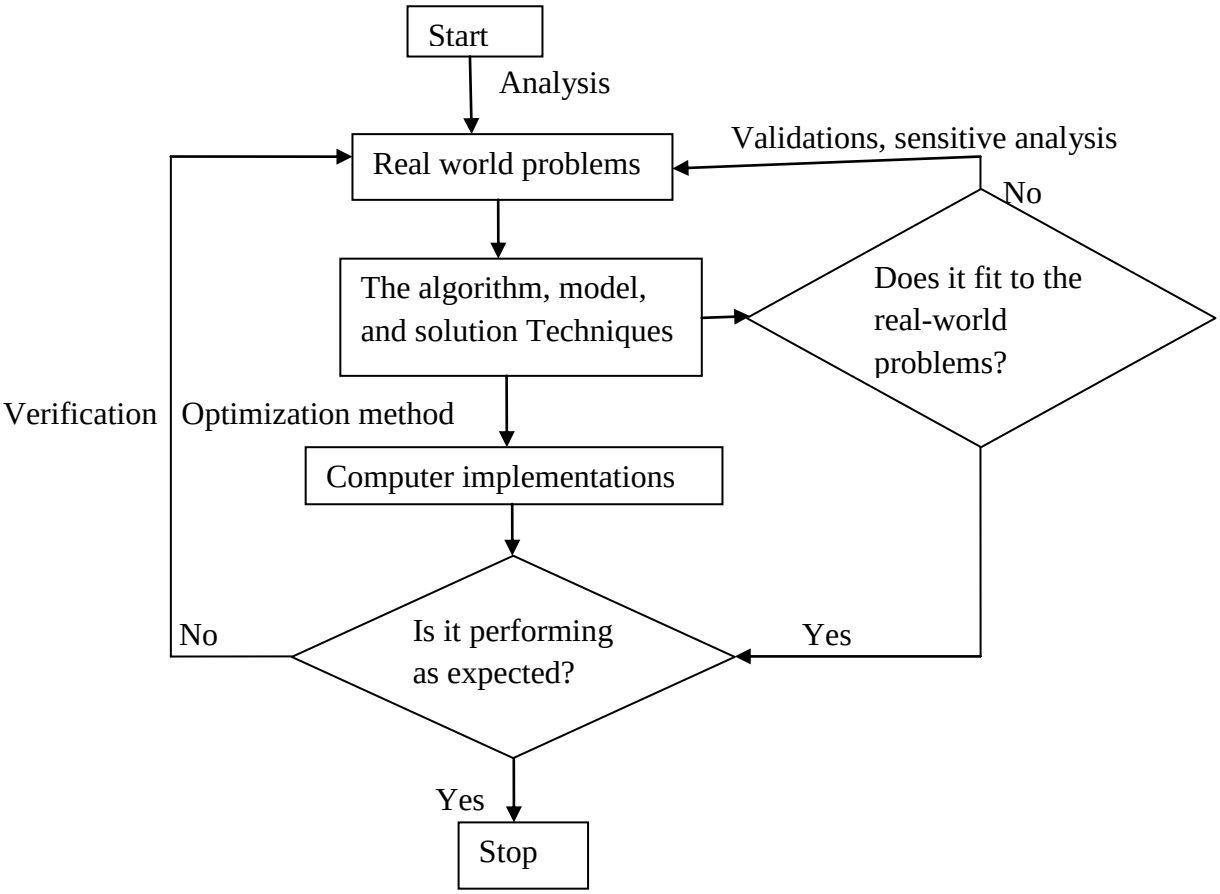


Figure 6: The optimization process

1. The process optimization begins by defining a real-world problem to extract some detail relevant information necessary to create a mathematical model. The aid of computer programs is tool for optimization technique and model development. It could be applied to the model with Figures-1; analysis is the first as shown by the arrow moving from the real-world problem box to the algorithm, model and solution techniques box. To build

effective and efficient optimization, mathematical model is necessary to extract the real details Focusing on the analysis process is critical because it lays bare crucial elements of the problem and it gives insights as to how to address the parking problem.

2. The use of optimization methods is the second process, as shown by the arrow moving from the algorithm, model and solution technique box to the computer implementation box. To get real solution for mathematical model, the knowledge of these optimization methods and their implementation procedure are essential. The verification process is used in order to be sure that the optimization method is performing as expected; the verification process is shown by the arrow moving from the computer implementation box back to the algorithm, model and solution technique box.
3. The last process is Validation and sensitivity analysis in which optimization process is completed by moving from the algorithm, model, or solution technique box to the real world problem box. Here; the results obtained are compared with the real world situation. This process determines whether the results are appropriate or the need of modification as well as the choice of other the solution techniques as necessary.

2.9 Different Strategies and Policies Regarding Parking

The developed country used different types of strategy and police to manage parking problem in the city. Some of strategy discussed in the following table (Dr. Kirti Mohan Sharma et al, 2017).

Table 1: Types of parking strategies

No	Strategies and Policies	Descriptions
1	Centralized Parking strategy	In the centralized parking system large number of people gathered at once parking place which we call a center for the parking and then travel by the help of other modes of transportation which are like E-rickshaw… etc. The centralized parking lot is good with respect to economic, environmental and urban design perspective but raise concerns for building occupants, such as lack of parking proximity.
2	Meters In Parking Lots	In metric parking system, using meters in parking it will help us to optimize turnover of parking space for priority customers. As we use parking meters its price deflects according to the market demand in which they raise charges of curb in peak hours in the parking lots.
3	Mixed Use Parking	In the mixed parking strategy when maximum demand arriving in the parking lot, the drivers requires shared parking in mixed use areas, these demand occurs at different times. Such as temples, churches, mosques etc. They should share their parking with the nearby residential parking lots and commercial establishments on the occasion of festival or religious functions. This strategy works effectively they provide a lot of parking space on the peak time to minimize congestion on the roads.
4	Shuttle Service	In the shuttle service promoted parking, the system introduces

	Promoted Parking	shuttle buses to reach final specific destination. In the system, customers use centralized parking to park their vehicles and then with the help of shuttle bus service commuters may reach their final destination.
5	Parking Freezes	In parking freezes system After certain time limit some parking areas in the neighborhood are not allowed to be used for the purpose of parking in the city especially in the residential streets. For instance, parking is not allowed in the residential streets close to city center after 5pm. The amount of parking required can be directly reduced through parking freezes that cap the total number of parking spaces in a particular district for the limited time.
6	Smart Parking	Smart parking a system that informs and navigates the driver about the free space available in the nearby parking area using smart sensors and Smartphone application, the resident may get a notification on his Smartphone about a free space that is at some distance from his home. Currently, many municipalities rely on old-fashioned parking standards that result in an abundance of parking at the cost of community's character and vitality. Smart parking approaches can address these issues through a variety of techniques by tailoring standards, managing demand and improving parking facility design.
7	Demand Reduction	The centralized and shared parking not only decrease the parking requirements but also provide ways to reduce excess parking supply. The Demand reduction strategy directly focusing on the reduction of parking demand by replacing parking spaces for bus stops or reserved parking spaces for carpooling, car sharing, etc. It is also possible to reduce the need for parking lot and the associated costs influencing the demand for parking. It can be achieved by increasing the price of parking or by promoting non-auto transport incentives.

3 Parking Statistics

Before taking any improvement measurement, data regarding availability of parking space, extent of its usage and parking demand is essential. It is also required to estimate the parking condition. Parking surveys are used to provide all necessary information. Since the duration of parking varies with different vehicles, several statistics are used to access the parking need. The following parking statistics are normally important.

Parking accumulation: It is defined as the number of vehicles parked at a given instant of time. Normally this is expressed by accumulation curve. Accumulation curve is the graph obtained by plotting the number of bays occupied with respect to time.

Parking volume: Parking volume is the total number of vehicles parked at a given duration of time. This does not account for repetition of vehicles. The actual volume of vehicles entered in the area is recorded.

Parking load: Parking load gives the area under the accumulation curve. It can also be obtained by simply multiplying the number of vehicles occupying the parking area at each time interval with the time interval. It is expressed as vehicle hours.

Average parking duration: It is the ratio of total vehicle hours to the number of vehicles parked.

$$\text{parking duration} = \frac{\text{parking load}}{\text{parking volume}}$$

Parking turnover: It is the ratio of number of vehicles parked in duration to the number of parking bays available. This can be expressed as number of vehicles per day per time duration.

$$\text{Parking turnover} = \frac{\text{Parking Volume}}{\text{No.Of Bays Available}}$$

Parking index: Parking index is also called occupancy or efficiency. It is defined as the ratio of number of bays occupied in time duration to the total space available. It gives an aggregate measure of how effectively the parking space is utilized.

$$\text{Parking Index} = \frac{\text{Parking Load}}{\text{parking capacity}} * 100$$

2.3.1 Parking Lot Capacity Determination

The vehicles accumulation profile determine accumulation amount of vehicles. This is important to determine number of accumulation, for a given time interval and the amount of parked vehicles area. The accumulation of vehicles in an area follows the principle of arrivals and departures of vehicles.

Theoretical parking capacity: Theoretical parking capacity is directly derived from vehicle accumulation profile and corresponds to the maximum value over the day. It is also possible to observe the maximum value for each hour of the day.

Estimation of raw parking capacity: the estimation of raw parking capacity must be done separately for on-street and outdoor parking. The raw on-street parking capacity is determined by calculating the number of parking spaces for each area. The number of parking spaces is measured by dividing the length of street where parking is allowed by the average length of a car. The following formula is used:

$$\text{Nspace} = \frac{\boldsymbol{L}-[(\boldsymbol{b}*\mathbf{5})+(\boldsymbol{e}*\mathbf{3})+(\boldsymbol{Tc}*\mathbf{15})+(\boldsymbol{i}*\mathbf{7})}{\boldsymbol{a}} \ldots\ldots \text{eq.(1) (Abdoulaye Diallo et al, 2012)}$$

Where,

L= average length of the stretch of road (m) b= number of terminal-fountain

e= number of driveways Tc= number of bus stops

i= number of spaces where there is a strict prohibition of parking

a = average space (linear) occupied by a parked car (m)

The parking road length of on-street parking road capacity is reduced by the following consideration factors:-

1. Terminal 5meters
2. Driveway 3 meters
3. Bus stop 15 meters and
4. Some forbidden space reduces 7 meters.

The constant values found for average parking space in this study varies depending on the following parking angle such as parallel parking,30°, 45°, 60° and 90° parking angles and the reduced value from the road are 7,4, and 3 meters respectively on the roads.

The preferred circulation system is one-way over two-way circulation for parking angle. And two-way circulation provided more parking spaces for circulation, drivers may park in the space of the opposite direction therefore blocking circulations and creating conflicts. Drivers may violate the one-way aisle for the 90-degree parking because the maneuvering space needed for such parking is enough for two-way circulation.

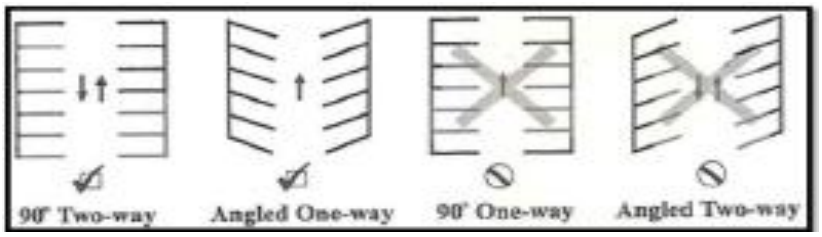


Figure 7: Suggested circulation configurations adapted **(Akmal s el al, 2014)**.

2.3.2 Parking control Unit

Parking Control Unit is the parking space used for a vehicle, which depend on vehicle dimension plus additional space needed for a vehicle to maneuver whose value depending on the parking angle. PCU of each vehicle can be obtained in the following.

Table 2: Types of vehicles and dimensions **(Said Munzir et al, 2010)**.

N0	Types of Vehicles	Width (M)	Parking width (M)	Length (M)	Parking length (M)
1	Motorcycle	0.8	1.3	1.9	2.4
2	Passenger car	1.5	2.5	4.1	5.1
3	Medium bus	2.1	3.1	6.0	7.0
4	Big bus	3.5	4.5	9.3	10.3
5	Truck	2.4	3.4	7.2	8.2
6	Small bus	1.6	2.6	4.1	5.1

3.1 Different Articles on Car Parking Systems

The following articles are discussed about the different types of parking system, parking problems, parking solution, formulated models related to parking and strategies of parking.

Table 3: different articles related of parking

Name of researchers	Title of the articles	Studies Methods	Focusing area of study	Final Output of the study
(Dr. Kirti Mohan Sharma et al, 2017)	Problem of Parking and their Possible Solutions with Special Reference to Kota City	By reviewing different articles and observations of the parking activities.	The focusing areas of the study are analysis of parking problems, causes for parking problems and how to minimize the traffic congestion in the city. The article try to develop the solution by reviewing the different parking police which are centralized parking police, specific time parking, banned parking on the street, shuttle service encouragement, price based parking and periodic parking(short-stay and long stay) and final try to recommended the solution for the city.	The final result of the paper show that the main reasons for parking problems and traffic congestion are migration of more people from rural area to urban area for the opportunity of job and for higher standard living and low development of infrastructure in the city .The study concluded that the city can be managed the parking problems by developing different traffic management police in the city, by encourage short term parking and by facilities the pedestrian movement.
(Aljoufie, 2016)	Analysis of Illegal Parking Behavior in Jeddah	Observational survey of the five selected areas.	The paper mainly concerned on analyze of illegal parking in selected commercial areas in Jeddah, drivers behaviors' and illegal parking management police in the city. The study comparing the weekday and weekend by dividing into three time period which are morning, afternoon and night time in the city.	The study results show that the illegal parking in the city is common both in weekday and weekend but in the weekend and mid night period time very high illegal parking in the city. Another result of the study indicates that awareness of drivers about illegal parking pressure on the transportation system and looking as legal activity.

(Thomas B et al, 2004)	PSOS, Parking Space Optimization Service	Using e-business concept	The focusing area of the paper is to develop the e-parking system to reducing parking problems and to regulating parking activities in the parking centers. This model able to optimize the parking space by providing information to the drives. This conceptual model consists of three web applications which are (CIA) channel manager. Integration manager and web applications	The result of the articles is web development for the purpose of information availability by (internet, mobile application for the seeking of accessibilities of parking space)drivers to reduce searching time to find free parking space, easily payment for the drivers and suppliers and minimizing of parking congestion and reducing environmental pollution and optimize space.
(Adam J. Pel et al, 2016)	Stochastic User Equilibrium Traffic Assignment With Equilibrated Parking Search Routes.	A Queuing Model	The Study focusing on the interdependency between parking search route flows, travel times and parking probabilities.	The study result show that, Queuing model is implemented and applied both to a number of experimental cases to verify its properties and to a real-life setting. Finally, try to illustrate its usefulness in parking route searching to minimize travel distance.
(Brooke, 2015)	Factors Influencing Urban On-Street Parking Search Time Using A Multilevel Modeling Approach.	Multilevel Modeling Approach	To investigate and compare the factors that influence drivers' on-street parking search time and its policy implications.	Introduction of future policy measures to reduce parking search activity.
FUMITAKA KURAUCHI	Simulation Analysis on the Evaluation of Parking Reservation System.	Dynamic Traffic Simulation Model	Parking Reservation (PR) system is proposed to disperse parking demands temporally.	Parking reservation system is really helpful for drivers who need to arrive at their destination on time. The effect of PR system may vary largely on where reserved car parks are located.
Ali Moradkhany	Minimizing Parking Search Time On Urban University	Introduces Bi-Objective Optimization Algorithm	The study is focusing on to minimize the parking search time and the number of parking trials to find a free space on urban university campuses due to daily commuters.	The study results, the parking demand can be efficiently distributed and the search time can be effectively reduced. The finally optimized class assignments will result in effective mitigation of the cruising flow due to reduction in the total number of parking trials.

(Serugendo et al , 2017)	Cooperative Multi agent System for Parking Availability Prediction Based on Time Varying Dynamic Markov Chains	Markov chain models	This study focusing on to Markov chain will be constructed and used to predict the next state of the available level of parking space. Since the demand for parking place varies and depends on time-related multi-agent-based for prediction of parking spot availability.	The study shows that an agent-based service combined with learning and prediction system, as a solution to ease parking place search and this solution reduce traffic congestion on road.And Agents predict the parking availability in a given parking garage, parking centers and communicate with other agents to produce a cumulative prediction.
(J.P.F. Charpin et al)	Optimization Model For Campus Parking Space Allocation	Using mathematical model	The study mainly considering of allocation of parking space to increase parking space usage, maximizing income of parking and minimize unhappiness of the drivers who has not have permanent parking spot in the parking area by considering the various criteria which are average distance from parking buildings, security of the parking and coverage area of parking.	The result of the article are developed the model that minimizing the unhappiness of the drivers if the parking space full occupied by the customer of the parking area. These models used to measure the degree of unhappiness of the drivers when there is not have available parking spot.
(Tian, 2011)	Optimized combination model and algorithm of parking guidance information configuration	A genetic algorithm	This study focusing on analyzing of drivers parking choice behavior and development of new parking guidance information system to minimize total travel time to find free parking spot in peak time and to smooth traffic flow.	The final output of the study show that the newly developed PGI model minimizing the total travel time to search free parking spot by distributing the drivers in to different parking zone by giving real information .

(Sisiopiku, 2015)	On-Street Parking On State Roads	Survey of questionnaire of drivers	The study of this article is focusing on the investigation of on-street parking effects on the road. The study try to explain the effects in the direction of safety, congestion of the roads, accessibility, traffic calming ,environmental effects and development and economic effects on the societies.	The final conclusions of the study show that on-street parking reduces road capacity by creating congestion on the city by closing the roads. Even on-street parking creates 20% of all urban car crashing and 5% peoples dead in the on-street parking when the drivers inter into car and exit time. According the stud on-street parking create impede the traffic flow and increase car crashing on the roads so that by reducing on-street parking we can increase road capacity in the city.
(Akmal s el al, 2014)	Parking Capacity Optimization Using Linear Programming	Linear Programming Techniques	This study focusing on the parking lot design factors such as special on parking angle because the parking capacity depend on and optimizing the space by considering the parking lot layout and dimension applied Integer Linear Programming to optimize	The final outputs of the study is comparing of the linear integer programming with the traditional AutoCAD and selecting the optimal parking angles that provide the maximum number of spaces (efficient capacity), so that linear integer programming is used because it given optimal parking angle .
(Joel, 2013)	Model and Solutions to Campus Parking Space Allocation Problem	Using space optimization models and CPLEX solver	The paper focusing on optimizing of the parking space for staff and students to reduce the walking distance from their parking area into the destination area in the campus by considering various parking area criteria such as distance between the parking lot and destination, security, covered parking and additional service , reserved and unnerved space. The paper evaluation of various parking space allocation models which are space allocation models, assignment models, travelling salesman models, meta-heuristic and genetic algorithm to minimize the misuse of the space in the parking facilities and	The final findings of the researcher is comparing of different optimization models and select the best model which are matching with real life situation in the campus environment. The study investigating that meta-heuristic algorithms indicate that the Successfully solving the parking allocation problem and can give solutions that are near optimal situation and minimize the walking distance and waiting time.

			minimize the penalty for the violation of the parking police.	
(Maric M et al, 2016/17)	parking search optimization in Urban Area	Adaptive Multi-criteria optimization model and simulation	This study focusing on the reducing of search time based on parking factors such as access for parking spot , time limit in the parking lot and pricing restriction of parking facilities to balance the parking demand with parking supply to avoid traffic jam in the city by considering of some assumption in the models.	The final conclusion of the study is reducing searching time by 70%.The researcher comparing by taking different assumption scenarios and decrease search time with information availability about the main car parking factors such as acceptable walking distance to final destination, parking price and driving time.
(Said Munzir et al, 2010)	Linear Programming for Parking Slot Optimization	Linear programming models, observations and field survey.	The focusing area of the article is to maximize the parking area capacity by considering the parking land availability. Based on the different constraints such as parking lot demand, accumulation capacity of the parking lot, and average parking duration of the drivers in the parking. In addition, the study focusing on the allocate of parking space to different vehicle types size and based on parking standard for allocation of each type of vehicles.	The final conclusion of the study is measuring of the satisfaction level by the comparison of the three parking area factors such as parking area accumulation capacity, average parking duration and both constraints. The optimal solution from the three scenarios' is parking accumulation gives the best satisfaction level to customers and if we considering parking space it gives the maximum parking space. And in the other way we considering average parking duration give fewer parking spaces.

(Peter van der Waerden et al, 2013)	Car drivers' familiarity with the parking situation around regional shopping centers	Home sent questionnaire	This study concerned about the car drivers familiarity with the parking lot in the direction of shopping center trips and relationships between the parking lot attribute and the car drivers familiarity with these parking lot.	The final result of study show that car drivers behavior are not familiar with available parking lot in the final destination(shopping centers) and the most influential attributes of the car parking lot are finding of free parking spot and distance to final destination .

2.5 Summary and Gap of Literature

The major findings of the articles reviews are summarized as the follows:-

- In study investigation most of the articles focusing on the model development to minimize parking problems such as searching time , walking distance to final destination, parking price and waiting time in queuing .
- Development of parking management police can be minimize parking problems, and the parking problems will be solved by developing information system to the drivers by mobile application and internet access.
- And the most literature optimization model focusing on minimizing of searching time, walking distance, parking price and waiting time in parking facilities.

As far as in study investigation, the articles may not consider the following areas:-

- The articles considering on the minimizing of the time, price and waiting time of the drivers on the parking lot but what about the parking space and how to increase utilization capacity of the parking area.
- Studies may not develop the models that are maximizing the existing parking space capacity to satisfy the drivers' needs. And rather the articles suggested development of parking technology and construction of new parking facilities.
- The studies can't consider how to optimize a few number of parking area in the city. Because, land cost in the cities are too much expensive and unavailability of the land. So that this thesis worked on the optimization of parking space by rearranging the position of cars by different angles and maximization of parking space in the city by developing mathematical LP models.

CHAPTER-THREE

3.1 Research Design and Methodology

3.1.1 Introduction

In this research design and methodology part discussed about data collection methods such as primary and secondary, questionnaire design data analysis tools and sample design for study. To achieve the objective of this research, the following research frames are used:-

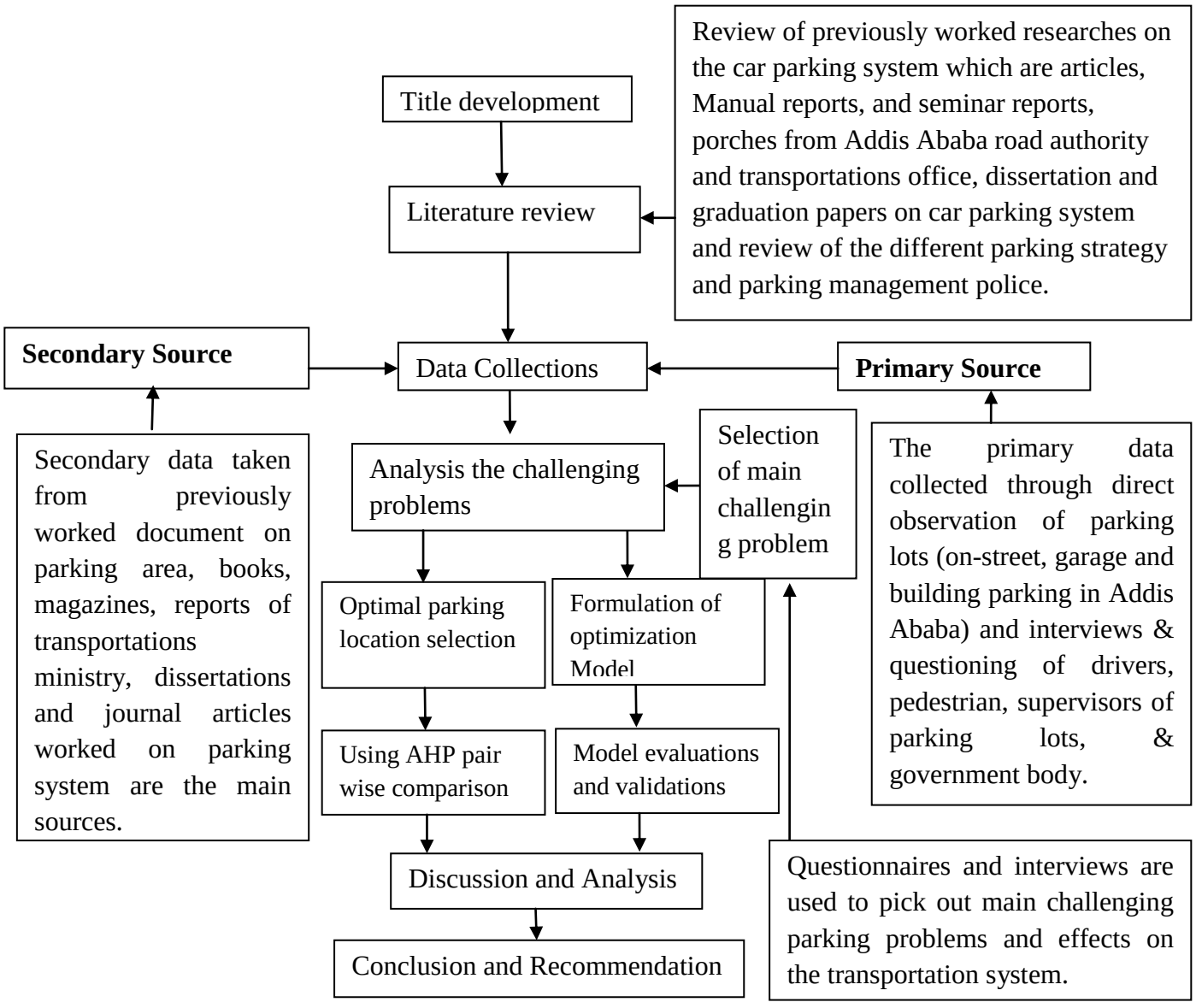


Figure 8: Research frame

3.2 Methodology of the Research

This thesis conducted to provide basic information about Addis Ababa car parking system for better management and to optimization of challenging problems in the city. By introduce space optimization model to optimize parking space to generate parking solution and reduce hindrance of traffic flow in the city. The deeply study conducted to assess the current parking related issue within the parking lot and A brief survey used to identify the main challenging problem in Addis Ababa. The study survey area was defined into specific parking location by the following procures:-

3.3 Literature Review

Different literatures such as journals, articles, graduation papers, dissertation papers, report manuals and books were reviewed which are related to parking and developed solutions to parking problem.

3.4 Data collection

This research used both qualitative and quantitative methods for conducting the research because the issues inbounded in this research would be related to quantitative as well as qualitative aspects. In this study different methods of data collection were employed, which can be collected or gained by two methods of data collection systems, these are primary data collection methods &secondary data collection methods. Interviews, direct & indirect observation of the parking activities and questionnaires are the primary data collection methods, the questionnaires have been developed in English and translated into local language Amharic and distributed to assess the general status of parking system in Addis Ababa

3.4.1 Primary Data Collection

1. **Questionnaire:** These questionnaires used to dig out the information from the drivers, pedestrian and government officials such as construction permit and control authority, Addis Ababa road authority and Addis Ababa transport city office about car parking system, parking space shortage effects on the transport system and the drivers feelings and opinions are very important to identity the main challenging and to prioritize the problem in the city.

2. **Interview**: The main purpose of interview used to collect data from the government responsible officials such as construction permit and control authority, Addis Ababa road authority and Addis Ababa city transport office about parking facility issue in the perspective of design consideration on the buildings(malls, shopping centers, and apartments),design consideration and site selection criteria for parking area ,and to identify parking space unavailability effects on the Addis Ababa transportation system and it was very important to obtain more relevant primary data about the overall activities, polices and strategies of Addis Ababa car parking system.

3.4.2 Secondary Data Collection

1. **Books and papers**: Review of books and research papers on the car parking system which are journal articles, Manual reports, books, journal and seminar reports, porches from Addis Ababa road authority and Addis Ababa city transportations office, project papers on the car parking lot development from Addis Ababa city transport office, dissertation and thesis papers on car parking system and review of the different parking strategy and parking management police in the world.

2. **Documents**: The Relevant documents data was collected directly from the Addis Ababa traffic and parking management office such as reports, manuals, worked project documents on the parking, and police documents of parking facilities from the government or parking area owners. In addition, Addis Ababa parking system standard document and other countries.

The secondary data which are relevant to the study were also collected in different offices. Some of the major offices contacted are:

1. Addis Ababa Road authority (AARA):-to collect the data about parking site selection criteria in Addis Ababa master plan and the standard of road length and width.
2. Addis Ababa city transport office:-to collect the data about parking facilities design consideration and parking area unavailability effects on the Addis Ababa city transport service.
3. Construction permit and control Authority:-to collect the data about required number of parking area and standard parking space in a building.

3.5 Questionnaire Design

This thesis survey was conducted by using self-completion questionnaires and was completed with the guidance of the researcher. This method was selected because there is higher possibility for the candidate to respond to the survey and the researcher is able to ensure that the respondent has understood the questions and the purpose of the research. In addition, the questionnaire is constituted with closed type, open type, multiple-choice, "Yes "and "No" and Likert type questions included to analyze the Addis Ababa parking system . During the design of the questionnaire, certain principles were taken into account in terms of attractiveness, clear language, reliability, consistence and relevance to the research objective. The questionnaire survey questions included question that were related to the parking characteristics, drivers decision behaviors, and police and strategy of city in parking system.

Table 4: Questionnaire Design

Questionnaire Design	Explanation
Questionnaire of the Research	Before the applied of the questionnaire, the questions were designed it would be able to address all the research questions. The use of questionnaire is to collect the quantitative data from the drivers and responsible body. It is an inexpensive and fast way to gather data from a potential large number of respondent (drivers).And then the researcher has chosen the questionnaires survey to the drivers and interviews with pedestrian and responsible government body to understand about Addis Ababa parking system.
Pilot Study	After completing the design phase of the questionnaire were pre-tested on a small population (drivers) before they reach the full sample. A pilot study helps the researcher to identify whether the questions derives the right information, test whether there are any words or phrase that confuse or offend the respondent and determine if the instructions are clear for the participants derivers.

3.6 Data Analysis tools

The analysis of the data from the interview , structured and semi structured questionnaire were carried out using descriptive statistics and the results of the open ended questionnaire and interview described by using the following analysis's tools.

1. MS EXCEL: the purpose in this thesis is to draw pie charts, histograms and to calculate drivers' questionnaire response data.
2. MINITAB: To draw the Pareto diagrams to prioritize the main car parking problems in Addis Ababa city based on the drivers' questionnaire response.
3. LINGO 17 Software: used to solve LP model and it can also solve more than 300hundrend variables and constraints.

3.7 Sampling Size Determination

The sample size used to determine the needs of participators in the research. The required sample size (n) was determined using standard statistical table by considering sample size for ±5% and ±10% precision levels. Where confidence level is 95% and p=0.05.

Table 5: Standard table to determine the sample size (Singh, Ajay S et al, 2014)

Size of population	Sample size(n) ±%5	Precision level(e) ± %10
500	222	83
1000	286	91
2000	333	95
3000	353	97
100,000	398	100
>100,000	400	100

Therefore, from the above standard table the selected sample size is 400 because the precision level is 100% and the size of population (drivers) greater than 100,000 in Addis Ababa because 70% of registered car found in the city.

This means that 400 divers asked for the investigation of all parking activities, to identify the major car parking problem in the city, police and strategy of the city and to determine driver's opinions and feelings on the car parking system in Addis Ababa city. Data were collected using well-structured questionnaire that has been given using self filled by the researcher or face to face interviewing with government responsible body, drivers and pedestrian. The questionnaire prepared in English language and then translated into local language (Amharic).

3.8 Data Analysis and Discussion

The main analysis and discussion that were done in this document are Analysis of the existing car parking system such as types of parking, accumulations capacity, parking police and strategy, and finding of optimal parking space for the Addis KETEMA sub-city. These are done to identify the real problems and to develop mathematical LP model and AHP methods that gives the optimal number of space that required for parking of each cars at each time period that improve the problems found from questionnaire and interviews from the drivers and responsible government bodies. Finally, compare the developed model output performance with the existing performance to see the possible improvements.

CHAPTER-FOUR

4.1 Existing Parking Analysis and Discussion

4.1.1 Introduction

In this chapter of the paper discussed about study area selection steps and existing parking system based on the questionnaire and interviews response and the main challenging problems discussed with graphs and tables to understand the existing parking system of Addis Ababa and what the feeling of the drivers are in the parking service in Addis Ababa.

4.2 Identification of study area

Weighted Factor Rating Method is to merge quantitative and qualitative factors. The factors are assigned weights based on relative importance or by referring standards from the developed country parking area selection criteria and weight age score by professionals and experts for each site using parking area selection criteria (S.Anil kumar et al, 2009). The parking area selection standard criteria and ranking by the design department engineers specialized in design of roads and parking facilities .The ranking has been given based on their professionals' skills, local consideration factors and considering internationals criteria and international value weight in the table 7. The experts considering local consideration location factors, weights of international standard from table 7, and scores values starts from (1 = lowest and 5 = highest) for ten sub-cities in Addis Ababa. The following table is showing the parking area selection criteria and selected score value by the experts from Addis Ababa Road Authority. As the experts decision the highest weighted score is selected as the best important study area?

Table 6: Weighting of sub-cities by Addis Ababa Road Authority (Shiferaw, 2014).

Parking area consideration Factors	**% of weight**	**Sub-Cities**									
		A. ketama	Bole	gullele	Ledeta	Nifasik	Kolf	yeka	Arad	Akaki	kirkos
Road links	16	5	4.5	4	5	4	4	3.5	5	4	5
Staff parking	15	4	4	3	3.5	3.5	3.5	4	4	3	4.5
Parking Lease or rent costs	15	5	4.5	4	4.5	4	4	4	4	4	4.5
Proximity to market or client	12	5	4.5	4	4.5	3.5	4	4	4	4	5
Customer or visitor parking	11	5	4	4	4	4	4	4	5	3.5	4
Proximity to labor supply	11	5	3.5	4	4	3.5	4	4	4	5	4.5
Rail or bus links	6	5	4.5	4	5	4	4	4	5	4	4.5
Proximity to goods or services	5	5	4.5	4	4.5	4	4	4	5	5	4.5
Traffic noise	3	5	3.5	3	4	3.5	3.5	3	4.5	5	4.5
Proximity to competitors	3	4	4	4	4	4	4	4	4	4	4
Air quality	3	2.5	4	3.5	3	3.5	3	3.5	3	3.5	3.5
Total weight		**474**	420	380.5	385.5	378	388	387.5	**436.5**	397	**454**

Result of analysis-1

The weighted score for this particular site is calculated by multiplying each factor's weight by its score and adding the results:

1. Weighted score of the location of ADDIS KETEMA = **474**
2. Weighted score of the location of KIRKOS sub-city = 454
3. Weighted score of the location of ARAD sub-city = 436.5

Therefore, from the above analysis result Addis Ketema Location **is** the best study area based on total weighted scores by the Experts and Engineers from Addis Ababa road Authority).

Table 7: Weighting of sub-cities by Addis Ababa parking management **(Shiferaw, 2014)**.

Parking area consideration Factors	**% of weight**	Sub cities									
		A. ketama	Bole	Gullele	Ledeta	Nifasi k	Kolf	yeka	Arada	Akaki	kirkos
Road links	16	16	5	5	4	5	4	4	3.5	5	4
Staff parking	15	15	3.5	4	4	4	3.5	3.5	4	4	3
Parking Lease or rent costs	15	15	5	4.5	4	4.5	4	4	4	4	4
Proximity to market or client	12	12	5	5	4	4	3.5	4	4	4	4
Customer or visitor parking	11	11	4.5	4	4	4	4	4	4.5	5	3.5
Proximity to labor supply	11	11	5	4	4.5	4	3.5	4.5	4	4	5
Rail or bus links	6	6	5	4.5	4	4	4	4	4	5	4
Proximity to goods or services	5	5	5	4.5	4	4.5	4	4	4	4.5	5
Traffic noise	3	3	5	4	3	4	4	3.5	3	4.5	4.5
Proximity to competitors	3	3	4	4	4	4	4	4	4	4	4
Air quality	3	3	2.5	4	4	4	4	4	3.5	3	4
Total weight		**461.5**	**441**	402.5	380	381	396. 5	387. 5	**434**	397	433

Result of analysis-2

The weighted score for this particular site is calculated by multiplying each factor's weight by its score and adding the results:

1. Weighted score of the location of ADDIS KETEMA = **461.5**
2. Weighted score of the location of BOLE sub-city = **454**
3. Weighted score of the location of ARAD sub-city = **434**

Therefore, Location ADDIS KETAMS is the best study area based on total weighted scores by the Engineers from (Traffic and parking management officers') result of analysis-2.

Therefore, Addis Ketema is selected to study because the highest weighted score value given by the engineers from design department comparing parking area selection criteria with the Addis Ababa city parking area selection criteria with international parking area selection criteria. So they are the relevant place to gather data about interaction between parking facilities and traffic flow. The Data gathered from these parking areas was used to analyze the existing parking behavior and that can be help to develop space optimization models to balancing demand and finding optimal parking location For Addis Ketema sub-city with AHP methods.

4.3 Analysis of the Questionnaire

The survey questionnaire are subjective and objective questions were prepared and used to assess the current parking behaviors and views and opinions about the current situation of car parking system in Addis Ababa. The purpose of the survey is to identify the main challenging problem of parking and to develop the solution to minimize the parking problems in the Addis Ababa city. The data has been collected randomly from the drivers. The following are the discussion part of the collected questionnaires.

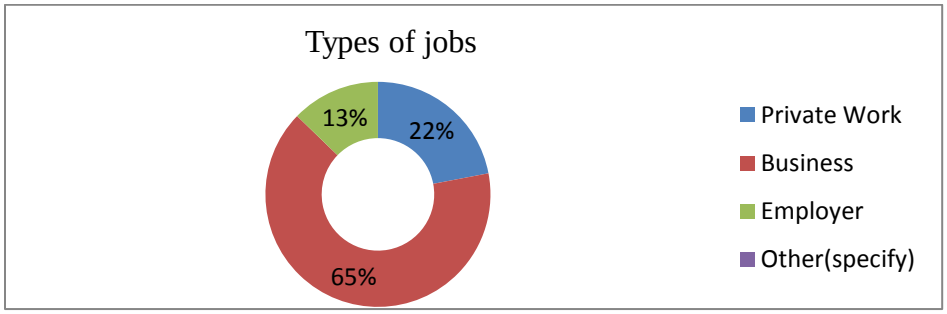


Figure 9: Types of Jobs

According to the result of questionnaire on the above diagram shows that 65% of parking users are business workers, 22% of parking users are private workers, and 13% parking areas used by employers in the city. The most parking lot users are a business workers compared with private works, and employers in Addis Ababa.

Q2: For the question of what type of parking facilities you should select and why?

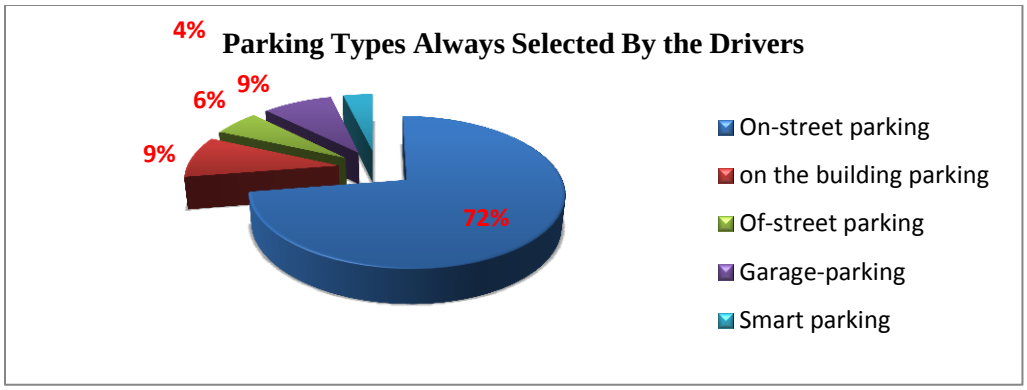


Figure 10: Types of Parking Facilities

According to the response of the drivers on the above pie-chart the result show that**72%** of the drivers' selected on-street parking area because of there are not have another parking area at destination, used for another purpose and unavailability of parking lot options like Of-street, smart, garage and building parking around their destinations and in the city. So that, according to drivers' response the building parking was used to another purpose for (store, supermarket and night clubs) in Addis Ababa. In addition, the pie-chart 9% of garage parking, 6% Of-street parking, 9%building parking and 4% of smart parking center are selected for the purpose of parking with drivers in the city.

Q3. What is your measurement if not have available spot in parking center?

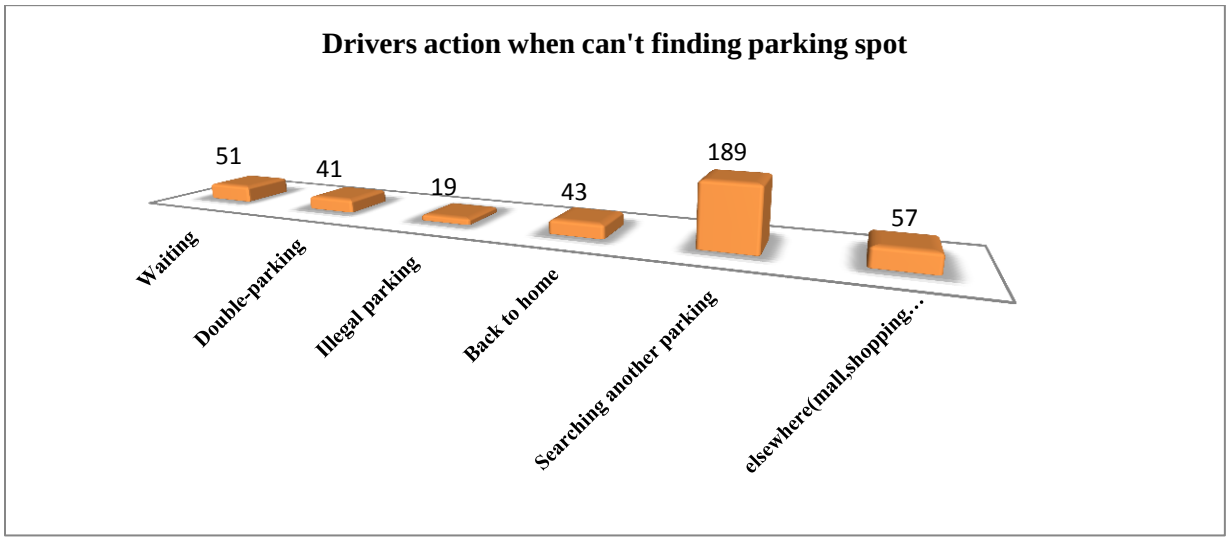


Figure 11: Drivers Action can't find parking spot

The analysis of the questionnaire on the Histogram shows that 189 drivers select another parking facilities when there are can't finding parking spot in their destination parking area and 57 drivers moving in to elsewhere such as malls, shopping centers to find parking space, 51 drivers waiting until finding free spot, 43 drivers back to home, 41 drivers double-parking, 19 drivers parking illegally on the roads. Therefore, the responsible body is concerning about construction and development of parking facilities to minimize searching time, waiting, double-parking, and illegal parking in the city.

Q4. What are the main parking lot criteria for the drivers?

Parking area criteria	code	Frequency of Response	Percentages (%)
Free space availability	A	182	46.4
Security and safety	B	151	38.5
walking time to final destination	C	20	5.1
walking distance to final destination	D	16	4.1
parking price	E	12	3.1
Nearest to roads, rail and markets	F	11	2.8

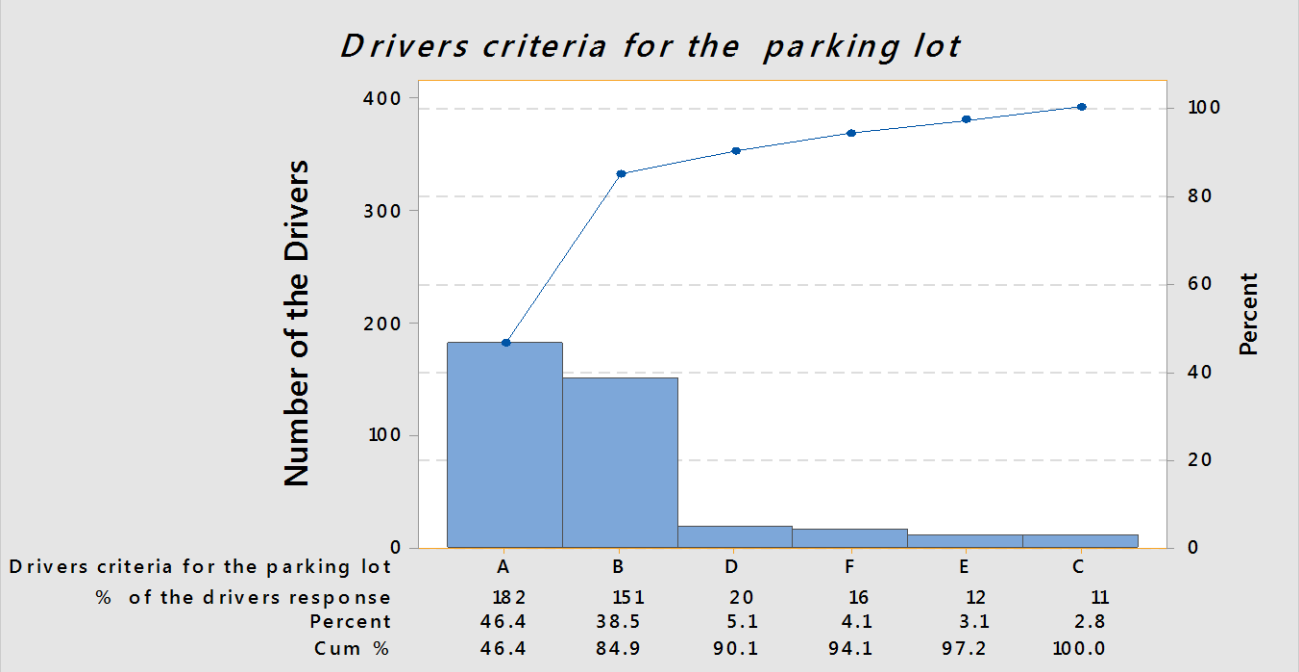


Figure 12: Prioritization criteria for Parking lot

The questionnaire result for the question of what are the prioritized criteria for parking lot are the 84.9% of drivers selecting free space availability and security and safety to their cars, and 5.1% for walking time to final destination, 4.1% walking distance to final destination, 3.1% for parking price and 2.8 % Nearest to roads, rail and markets on the Pareto diagram.Therefore, the Addis Ababa city concerning about the parking space for the cars to fulfills the demand of the drivers.

4.4 Analysis of the Interview

The interview discussion were made with different organization such as Addis Ababa road authority, Addis Ababa transport office, land banking officers and Addis KETAMA master plane developers about parking system in city. The response from the respondents about the interview questions and the result from the questionnaire discussed as the following:-

Part-one: Interview with Addis Ababa road authority

Table 8: Analysis of Interviews

No	**Questions**	**Response**
Q1	Which locations are appropriate for parking lot in Addis Ababa and why?	According to the design engineers from Addis Ababa road authority workers response for the question of which location are appropriate for the construction of parking lot are market areas, shopping locations, banking centers ,high rise buildings, and around higher institution are suitable location to parking facilities. Because of, most of the time market area, shopping center, commercial area, malls, and different institution are visited and crowded by the drivers and people.
		Response
Q2	Are there enough car parking places in Addis Ababa? If no, what are the main causes of the shortage?	The respondent said that it has not had enough parking lots place in city. Because, the parking space are not considered in the previews master plan of Addis Ababa. So that it's difficult to find parking space for the drivers as the result the drivers parking their car illegally and double-parking on the roads. The respondents said that in the previews master plan included only the terminal and depot of the bus.

		Response
Q3	Would you please tell me the car parking area shortage effect on Addis Ababa traffic flow?	The respondents' said that the parking area unavailability effects on the Addis Ababa traffic flow are blocking the road by double-parking on the roads, creates congestion on the roads, illegal parking on the roads, blocking the passage way of ambulance, taking too much time to search another parking area, increase consumption of oils, and taking too much time to arrive final destination.
		Response
Q4	What are your organization parking locations selection criteria?	According to the respondents we have not parking area selections criteria. But our organization have the taxi bay location selections' criteria which are junction of roads (four leg, roundabout, interchanges), around the market centers, and at higher bus and taxi loading and unloading demand location such as condominium locations.
		Response
Q5	How can be improved the service of parking in Addis Ababa?	The respondent said that by considering parking space in the master plan and land use plan in the city and enforcing highs raise building developers either to leave some free space in front of their building or to build basement parking for their customers for parking purpose to improve the service.

Part-two: Interview with Addis Ababa transport and parking project management officers.

Table 9: Interview Analysis of Addis Ababa transport and parking management office

No	Questions of the interviews	Response
Q1	What are the main parking area selection criteria in Addis Ababa city?	According to the parking project managers (engineers) from traffic and parking management office workers response for the main parking area selection criteria are parking demand, site suitability for development of parking facilities, distance from intersections of roads, land use issue and distance from the main roads.
Q2	What types of strategy and police provided to solve the current parking practice in Addis Ababa? Would you please describe how Addis Ababa city implement them?	The respondents said that the best strategy is providing adequate parking space in the city's master plan. And the implementation procures of parking strategy are by developing good parking management police, increase the participation of private sector in the development of parking facilities and administration of the city can be looking parking as a part of infrastructural in the city.
Q3	Would you please tell me the car parking area shortage effect on Addis Ababa traffic flow?	According to the parking project construction mangers engineers idea about the parking shortage effect on the traffic flow are narrowing of the roads that creates traffic jam in the city, accidents, and high carbon emission to the environments are the main parking space un availabilities effects in the traffic flow of Addis Ababa.
Q4	Which locations are appropriate for the location of parking lot based on your opinion in the city and why please mention some reasons?	The respondents said that all locations need to have parking lots. But priory should be given for commercial and service areas. This is because, relatively a high parking demand exists there and shortages of parking lots effects were observed in those areas.

Q5	Are there enough car parking places in Addis Ababa? If no, what are the main causes of the shortage?	The respondent said that No, the main cause of shortage are less value were taken in the past, the city administration not considering parking space in the master plan, and non-profitability of the sector for private sectors.
Q6	How can be improved the service of parking in Addis Ababa?	According to the respondents, the service will be improved by using recent parking management system and technology, Government and sub-city included parking space in the master plan, and by developing parking infrastructures.

4.1.3 Summaries of interview and Questionnaire

The response given by the drivers, Addis Ababa Road Authority, traffic and parking management officers and Addis Ketema sub-city(master plan developers and land banking officers)for the questions of questionnaire and interviews about car parking were summarized as the following:-

Addis Ababa Current parking situation

The Addis Ababa current situation are difficult to find parking space because of parking space used for social purpose, and government not considering about parking space and shortage of land in the city, previews master plan of the city not concerning about parking space, Government concern very poor to develop parking infrastructure in the city, roads are congested due to illegal parking and double-parking in the city, Due to availability of parking lot the drivers park their car on the on-street parking, illegally parking and moving long distance to search parking spot in the city, and parking site selection criteria considering commercial and highest pedestrian concentration area only.

Addis Ababa city main challenging problems

The Addis Ababa main challenging problems are finding of parking lot around their destination in the city, Congestion of roads due to double-parking and On-street parking , previews roads design not concerning parking area, High rise building parking basement used to another

purpose such as store, supermarket, etc, Increase accidents for the pedestrians by blocking the walking ways ,and Not have enough parking lot around market area, shopping, malls, and business center due this the drivers loss their time and money by searching another parking lot.

Suggested solutions for Addis Ababa city parking problems

The suggested solution for Addis Ababa parking problems are Government and sub-city administration included parking space in their master plan, Government enforcing high rise building developers either to leave some free space in front of their building for parking purpose or to build basement parking for their customers, and government encourages private investors to participate in the sectors.

Recommended Parking Location for Addis Ababa city

The recommended parking locations for Addis Ababa city are Commercial and service areas. Because, relatively a high parking demand exists, Parking required at the higher institution, around stadiums, and high rise building, loading and unloading location such as condominium, and Parking required at the congested area such as market center and commercial areas.

Addis Ababa city should be considered the following Parking location selection criteria

The suggested parking location selection consideration criteria are Proximity to Road junctions, Proximity to railway and bus station ,Proximity to market and commercial areas, Proximity to service areas, Cost of land and Future purpose of the area, and Environmental condition (air quality and noise pollution).

CHAPTER-FIVE

5.1 Locating Optimal Parking Area and Space OptimizationModel

5.1.1 Introduction

One of the difficult decisions in car parking system is locating the optimal parking area and how to maximize the parking space capacity in the city. This parking area selection decisions considering different factors such as road junctions, availability of staff parking area ,parking land cost, proximity to market, parking area availability to customers or visitors, proximity to labor supply, proximity to rail or bus stations , proximity to goods or services , traffic noise , proximity to competitors, and air quality. Finding of optimal parking location in the city is difficult situation for the city administrations so that the first models used to find optimal parking location for Addis-Ketema sub-city by considering parking location selection factors, future purpose of the lands and 12 free spaces in Addis-Ketema sub-city. The second model objective is to maximize the existing on-street parking capacity by considering different constraints such as road length and width, parking angles, average parking duration and vehicles size.

5.2 Part I: To Select Optimal Parking Location

The needs for parking spaces is usually very difficult in city where land used for different purpose such as for business, residential, commercial activities and for service and manufacturing area .So that find of the solution for parking space is not simple, since the allocation of available parking space will depend on the goals of the community which the traffic engineer must take into consideration to solve the parking site selection problem.

The analytical hierarchy process (AHP) is developed by Thomas Saaty, and is a method for ranking decision alternatives and selecting the best one when the decision maker has multiple goals, criteria and sub-criteria and alternatives to find best decisions on the situations. AHP method answers the question "Which one?" Is the best from the alternatives? (Taylor, 2006).Analytical Hierarchy process (AHP), which has the ability to analyze a lot of parameters simultaneously in parking site selection processes. The following are the AHP solution procures (R. BANUELAS et al, 2004).

5.2.1Analytical Hierarchy Process (AHP) Procures

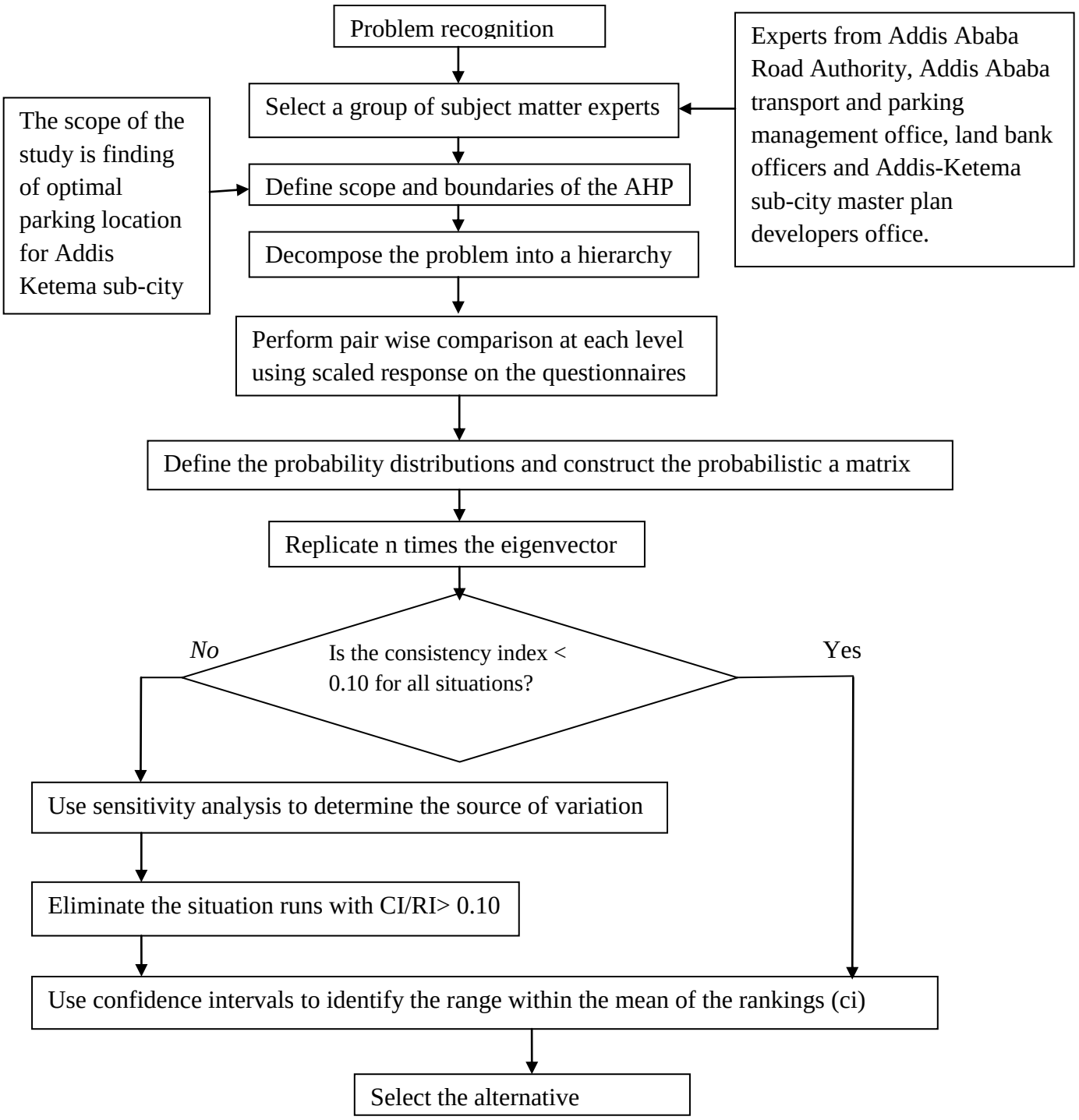


Figure 13: Approaches Of AHP Methods Adapted **(R. BANUELAS et al, 2004)**.

5.2.2Criteria and Sub-Criteria of Parking Locations

The following table show that the parking area selection criteria and sub-criteria.

Table 10: Criteria and Sub-criteria

No	Criteria	Sub- criteria
1	Location	Nearest to market/shopping centers/malls/religious area/stadiums etc.
		Proximity to road links and rail ways
		Proximity to commercial areas, and goods and service area
2	Parking lot size	Parking capacity of vehicles in the parking lot
		The volume of the land
3	Cost	Land rent or lease cost and parking price
4	Demand	Based on, easy to accesses, and security and safety of the parking zone
5	Environment	Noise and pollution of air quality
6	Land purpose	What is the purpose of this free space? (For instance, for mixed residence, for high density mixed residence, and for micro and small scale enterprise.

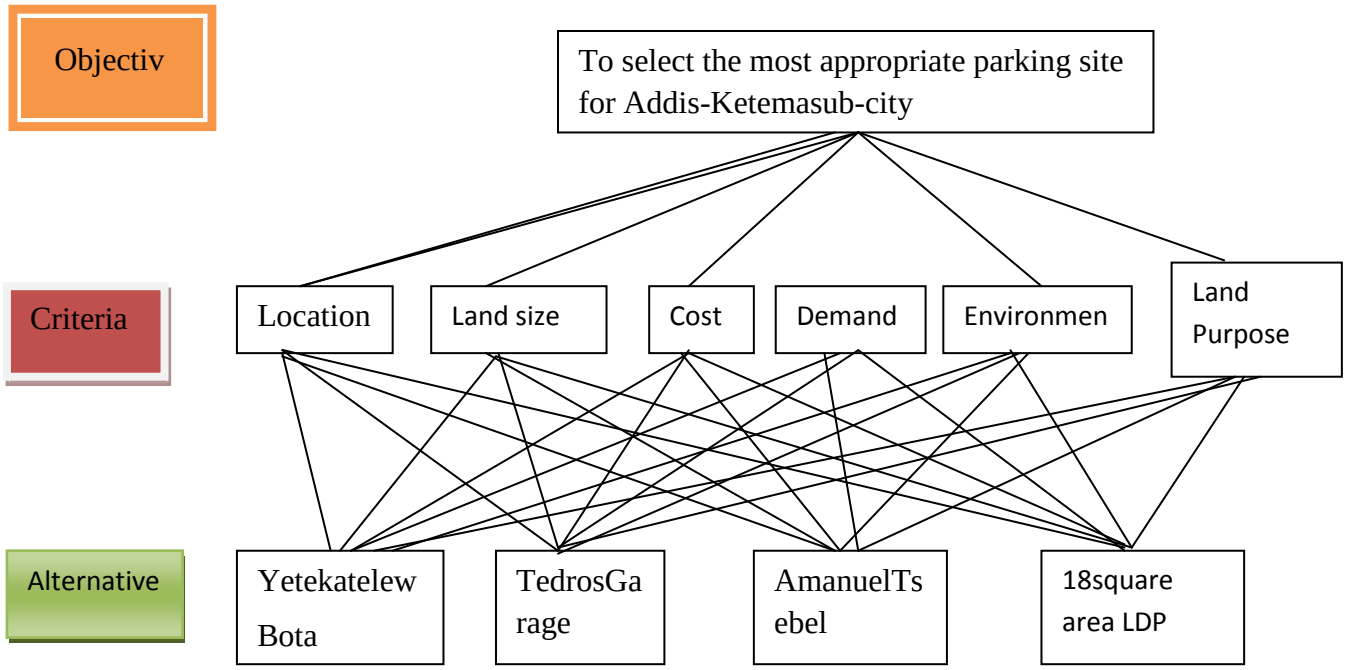


Figure 14: Structure of AHP Methods

5.2.3Parking Locations and Special Characteristics

Table 11: parking location characteristics

No	Name of locations	Area in (m.sq)	Land purpose	**Special Characteristics**
1	18square area LDP	776	for high density mixed residence	Nearest to kolife market center, road junction of 18square, and different banks.
2	yetekatelewbota	684	for micro and small scale enterprise	Nearest to church, market centers, micro and small scale enterprise building, police station, administration of Werda 10, Banks, international school, and elementary and high school
3	Tedros garage	1753.82	for existing mixed residence	Nearest to hospital (Amanuel hospital), condominiums (Amanuel), banks, coffee board and micro and small scale enterprise building.
4	AmanuelTsebel	2731	for existing mixed residence	Nearest to Amanuel church, police camp, Amanuel hospital, Amanuel condominiums, Bilal mosque, banks and EhillBernda.

5.2.4Experts Sample size Determinations

To calculating the sample size we used the formula. The formula used a 95% confidence level and precision level p=0.05 and the sample size used to determine the needed amounts of experts in decision makingprocess (Israel, 1992).

$$\boldsymbol{n = \frac{N}{1+N(e)^2}}$$

Where,n = smaple siz, $N =$
number of population from AATPMo, AARA, and AKSSMPD, and e = level of precisions.

$$n = \frac{N}{1+N(e)^2} = \frac{3AATPMO+6AARA+2AKSSMPD}{1+3AATPMO+6AARA+2AKSSMPD(0.05)^2}$$

Sample size (n) =7.096 ≈ 7 experts are needed for the decision making process.

Table 12: The standard Preference scale for pair wise comparisons

Preference Level	**Numerical Value**
equally preferred	1
Equally to moderately preferred	2
moderately preferred	3
moderately to strongly preferred	4
strongly preferred	5
strongly to very strong preferred	6
very strongly preferred	7
very strongly to extremely preferred	8
extremely preferred	9

1. Pair wise comparison matrix showing preferences for the six parking area selection criteria in terms of overall goals of the AHP model.

Criteria	locations	land-size	cost	demand	environment	land purpose
locations	1	5	8	7	2	4
land-size	1/5	1	9	8	3	2
cost	1/8	1/9	1	4	2	5
demand	1/7	1/8	¼	1	3	6
environment	¼	1/3	½	1/3	1	2
land-purpose	¼	½	1/5	1/6	½	1
sum	1.968	7.07	18.95	20.5	11.5	20

2. Sum and divide each value by the corresponding sum values in each column.

Criteria	locations	land-size	cost	demand	environment	land purpose	**average weight**
locations	0.508	0.707	0.422	0.341	0.174	0.2	0.392
land-size	0.102	0.141	0.475	0.390	0.261	0.1	0.245
cost	0.064	0.016	0.053	0.195	0.174	0.25	0.125
demand	0.073	0.017	0.013	0.049	0.261	0.3	0.119
environment	0.127	0.047	0.013	0.016	0.086	0.1	0.065
land-purpose	0.127	0.071	0.011	0.008	0.043	0.05	0.052

1. Pair wise comparison matrix showing preferences for the four parking area in terms of parking locations.

location	YetekatelewBota	Tedros garage	AmanuelTsebel	18square area LDP
YetekatelewBota	1	6	5	4
Tedros garage	1/6	1	4	5
AmanuelTsebel	1/5	¼	1	6
18square area LDP	¼	1/5	1/6	1
sum	1.117	7.450	10.167	16

2. Sum and divide each value by the corresponding values sum in each column.

location	Yetekatelew Bota	Tedros garage	AmanuelTsebel	18square area	average weight
YetekatelewBota	0.895	0.805	0.492	0.25	0.611
Tedros garage	0.149	0.134	0.390	0.313	0.247
AmanuelTsebel	0.180	0.034	0.098	0.375	0.172
18square area	0.224	0.026	0.016	0.063	0.082

1. Pair wise comparison matrix showing preferences for the four parking area in terms of parking land-size.

land-size	YetekatelewBota	Tedros garage	AmanuelTsebel	18square area LDP
YetekatelewBota	1	5	2	3
Tedros garage	7	1	6	5
AmanuelTsebel	½	1/6	1	6
18square area LDP	1/3	1/5	1/6	1
sum	8.833	6.367	9.167	15

2. Sum and divide each value by the corresponding values sum in each column.

land-size	Yetekatelew Bota	Tedros garage	AmanuelTsebel	18square area	average weight
YetekatelewBota	0.113	0.785	0.218	0.200	0.482
Tedros garage	0.840	0.157	0.654	0.333	0.558
AmanuelTsebel	0.056	0.026	0.110	0.4	0.191
18square area	0.037	0.030	0.018	0.067	0.059

1. Pair wise comparison matrix showing preferences for the four parking area in terms of land cost.

land cost	YetekatelewBota	Tedros garage	AmanuelTsebel	18square area LDP
YetekatelewBota	1	5	4	2
Tedros garage	1/5	1	5	6
AmanuelTsebel	¼	1/5	1	5
18square area LDP	½	1/6	1/5	1
sum	1.65	6.367	10.2	14

2. Sum and divide each value by the corresponding values sum in each column.

land cost	Yetekatelew Bota	Tedros garage	AmanuelTsebel	18square area	**average weight**
YetekatelewBota	0.606	0.785	0.290	0.142	0.456
Tedros garage	0.120	0.157	0.490	0.428	0.299
AmanuelTsebel	0.150	0.030	0.098	0.357	0.159
18square area	0.303	0.026	0.019	0.070	0.105

1. Pair wise comparison matrix showing preferences for the four parking area in terms of demand criteria.

Demand	YetekatelewBota	Tedros garage	AmanuelTsebel	18square area LDP
YetekatelewBota	1	4	5	2
Tedros garage	¼	1	4	3
AmanuelTsebel	1/5	¼	1	5
18square area	½	1/3	1/5	1
sum	1.95	5.580	10.2	11

2. Sum and divide each value by the corresponding values sum in each column.

Demand	YetekatelewBota	Tedros garage	AmanuelTsebel	18square area	**average weight**
YetekatelewBota	0.510	0.717	0.490	0.180	0.474
Tedros garage	0.128	0.179	0.390	0.273	0.243
AmanuelTsebel	0.103	0.045	0.098	0.455	0.175
18square area	0.256	0.06	0.020	0.091	0.107

1. Pair wise comparison matrix showing preferences for the four parking area in terms of environment criteria.

Environment	YetekatelewBota	Tedros garage	AmanuelTsebel	18square area LDP
YetekatelewBota	1	2	4	3
Tedros garage	1/2	1	6	4
AmanuelTsebel	¼	1/6	1	2
18square area	1/3	¼	½	1
sum	2.083	3.417	11.5	10

2. Sum and divide each value by the corresponding values sum in each column.

Enironment	YetekatelewBota	Tedros garage	AmanuelTsebel	18square area	**average weight**
YetekatelewBota	0.480	0.585	0.348	0.3	0.428
Tedros garage	0.240	0.292	0.522	0.4	0.364
AmanuelTsebel	0.120	0.048	0.087	0.2	0.114
18square area	0.160	0.073	0.043	0.1	0.094

1. Pair wise comparison matrix showing preferences for the four parking area in terms of land purpose criteria.

land purpose	YetekatelewBota	Tedros garage	AmanuelTsebel	18square area LDP
YetekatelewBota	1	5	4	3
Tedros garage	1/5	1	2	3
AmanuelTsebel	½	½	1	2
18square area	1/3	3	½	1
sum	2.03	9.5	7.5	9

2. Sum and divide each value by the corresponding values sum in each column.

land purpose	YetekatelewBota	Tedros garage	AmanuelTsebel	18square area	**average weight**
YetekatelewBota	0.493	0.0526	0.533	0.333	0.353
Tedros garage	0.098	0.105	0.267	0.333	0.201
AmanuelTsebel	0.246	0.053	0.133	0.222	0.164
18square area	0.164	0.316	0.067	0.111	0.165

Finally, developing an overall priority ranking

Criteria	locations	land-size	cost	demand	environment	land purpose		**Ranking criteria**
YetekatelewBota	0.611	0.482	0.456	0.474	0.428	0.353	*	0.353
Tedros garage	0.247	0.558	0.299	0.243	0.364	0.201		0.201
AmanuelTsebel	0.172	0.191	0.159	0.175	0.114	0.164		0.164
18square area	0.082	0.059	0.105	0.107	0.094	0.165		0.165
								0.065
								0.052

An overall score for each site is computed by multiplying the values in the criteria preference vector by the preceding ranking criteria matrix and summing the result, as follows:

1. Over all parking site (YetekatelewBota) priority

   = [0.611*0.353+0.482*0.201+0.456*0.164+0.474*0.165+0.428*0.065+0.353*0.052]

   =0.456

2. Over all parking site (Tedros garage) priority

=[0.247*0.353+0.558*0.201+0.299*0.164+0.243*0.165+0.364*0.065+0.201*0.052]

   =0.30

3. over all parking site (AmanuelTsebel) priority

=[0.172*0.353+0.191*0.201+0.159*0.164+0.175*0.165+0.114*0.065+0.164*0.052]

=0.16

3. all parking site (18square area) priority

=[0.082*0.353+0.059*0.201+0.105*0.164+0.107*0.165+0.094*0.065+0.165*0.052]

=0.084

The four parking sites, in order of the magnitude of their scores with experts, result in the following AHP ranking orders in the table:

Name Of Locations	Score Values
YetekatelewBota	0.456
Tedros garage	0.30
AmanuelTsebel	0.16
18square area	0.084

AHP analysis objective is to find optimal parking location by considering parking area selection criteria and sub-criteria such as location of site, size of land, land cost, demand of location, environment conditions, and land purpose. Based on AHP analysis result **Yetekatelew Bota** area selected as the site for the parking location, and Tedros Garage second, Amanuel Tsebel third and 18 square area fourth are recommended for parking location for Addis-Ketema sub-city. Rely on this result to make its parking site selection decision, Yetekatelew Bota must have confidence in the judgments it made in the pair wise comparisons, and it must also have confidence in AHP.

5.2.5Consistency checking of AHP model

To check the consistency index (CI) for the developed AHP model, by their pair wise comparisons for the six parking site selection criteria. This matrix, shown as follows, is multiplied by the preference vector for the criteria:

Criteria	locations	land-size	cost	demand	environment	land purpose		**average weight**
Locations	0.508	0.707	0.422	0.341	0.174	0.200		0.390
land-size	0.102	0.141	0.475	0.390	0.261	0.100		0.245
Cost	0.064	0.016	0.053	0.195	0.174	0.250	*	0.125
Demand	0.073	0.017	0.013	0.049	0.261	0.300		0.120
environment	0.127	0.047	0.013	0.016	0.086	0.100		0.070
land-purpose	0.127	0.071	0.011	0.008	0.043	0.050		0.050

The product of the multiplication of this matrix and average weight is computed as follows:

1. land location
   =[0.508*0.390+0.707*0.245+0.422*0.125+0.341*0.120+0.174*0.070+0.200*0.050]
   = 0.488
2. land size
   =0.102*0.390+0.141*0.245+0.475*0.125+0.390*0.120+0.261*0.070+0.100*0.050]
   = 0.204
3. cost =[0.064*0.390+0.016*0.245+0.053*0.125+0.195*0.120+0.174*0.070+0.25*0.050]
   = 0.084
4. demand
   =[0.073*0.390+0.017*0.245+0.013*0.125+0.049*0.120+0.261*0.070+0.30*0.050]
   = 0.073
5. environment
   =[0.127*0.390+0.047*0.245+0.013*0.125+0.016*0.120+0.086*0.070+0.100*0.050
   = 0.076
6. land purpose
   =[0.127*0.390+0.071*0.245+0.011*0.125+0.008*0.120+0.043*0.070+0.050*0.050]
   = 0.075

Next, we divide each of these values by the corresponding weights from the criteria preference vector:

$\frac{0.488}{0.039}$ = 12.500 $\frac{0.730}{0.120}$ =6.083

$\frac{0.204}{0.245}$ = 0.833 $\frac{0.076}{0.070}$ =1.086

$\frac{0.084}{0.125}$ = 0.672 $\frac{0.075}{0.050}$=15.000

Therefore, sum of the divided value= [12.500+0.833+0.672+6.083+1.086+15] =36.074

In the above AHP decision making analysis, YetekatelewBotawere a perfectly consistent decision, then each of these ratios would be exactly six. The consistent determined by summing the average value and dividing by six criteria:

$\frac{36.074}{6}$ =6.012

The consistency index, CI, is computed using the following formula:

$$Ci = \frac{6.012 - n}{n}$$

Where

$$\text{n} = \text{number of criteria compared}$$

6.012= the average value

$$Ci = \frac{6.012-6}{4} = 0.003$$

If CI = 0, then **Yetekatelew Bota** would be a perfectly consistent decision making in the AHP model. But, Yetekatelew Bota is not perfectly consistent. The next step is checking of inconsistency that is acceptable.

An acceptable level of consistency is determined by comparing the (CI) to a random index (RI) which is the consistency index of a randomly generated pair wise comparison matrix. The RI has the values shown in table depending on the number of criteria (n=6) being compared (Taylor, 2006).

n	2	3	4	5	6	7	8	9	10
RI	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.51

The degree of the consistence for the pair wise comparison in the decision making criteria matrix is determined by the computing the ratio of Ci and RI.

$$\frac{Ci}{RI} = \frac{0.003}{1.24} = 0.0024$$

Therefore, the degree of consistency is satisfactory if $\frac{Ci}{RI} \leq 0.1$

Therefore, YetekatelewBota is the optimal parking location based on the criteria in the AHP method. This indicates that selected location is nearest to final destination, market centers, service providers, and commercial area.

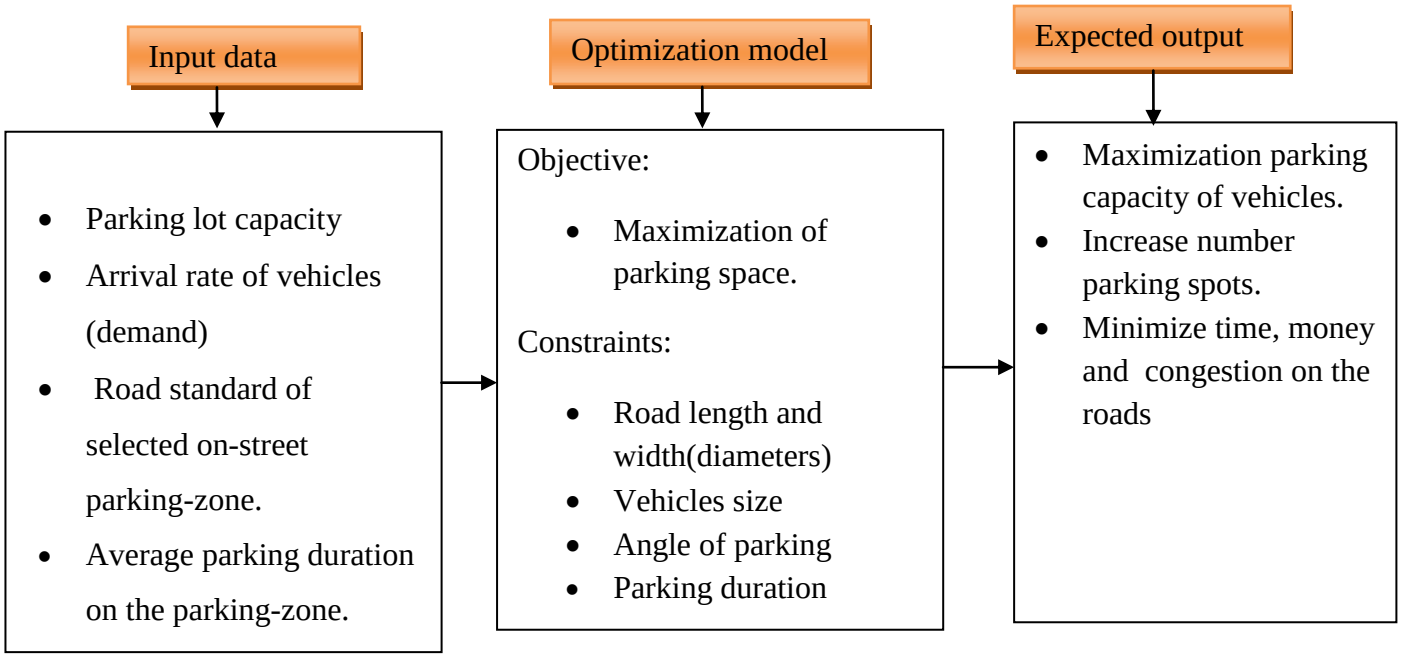
5.3 Part II: Model Formulation for Parking Space Optimization

Finding of parking space is difficult situation for drivers in the city. So that parking space optimization model used to minimizing this parking space problems by developing model. The model objective is to maximize the existing on-street parking capacity by considering different constraints such as road length and width, parking angles, average parking duration, arrival rate of vehicles, vehicles size and considering different assumptions.

The optimization models are linear programming, MILP and nonlinear programming (LP). Integer programming (IP) required additional requirement that is the variable in the model are $a_1 \ldots . a_n$ have to be integer, Mixed integer linear programming required only some of the variable are required to be integer, Non-linear Programming(NLP) included some process solving a programming problem subject to certain constraints, over a set of unknown real variables, but where some of the constraints or the objective function are non-linear (Pinedo, 2005) but linear programming is formulated as a linear programming problem because it can optimizing scare resource and the decision variable are $(a_1 \ldots ., a_n)$ Real number and objective and constrain equations are linear so that linear programming are selected. The Space optimization model formulated by (Said Munzir et al, 2010)and its model constraints consist of average parking accumulation and average parking duration. But in this research paper considered addition constrains which are arrival rate of vehicles and parking area considered by angles parking Model formulation considering the following assumptions:

1. The on-street parking locations parking capacity is known. Where, j=1,2,….,60
2. The vehicles arrive at the on-street car parking-zone follows as a Poisson distribution with arrival rate of vehicles per15 minutes and their average parking duration in 15 minutes interval is considered for all types of vehicles.
3. The vehicles types for passengers cars and motorcycles their size are assumed to be smaller than a given parking spots and for vehicle type for truck are assumed to be greater than the parking spot.

5.3.1 Mathematical Model



5.3.2 Definition of Terms Used in the Model

i =Types of vehicles (Trucks, Passenger car, and motorcycle), where$i$ =1, 2, and 3

j =Number of parking spot at on-street parking lot, where j= 1, 2, 3,……,60

$a_{i,j}$= Parking area for each type of vehicles (i) at parking lot with parking spot(j).

$A_{i,j}$ =Total parking area capacity for each type of vehicles (i) at parking lot (j)

C_x, C_y, and C_z = parking area utilization for the three types vehicles(trucks($a_{1,j}$), passengers car($a_{2,j}$) ,and motorcycles($a_{3,j}$)) in the parking lot.

$T_{di,j}$= Average parking duration of each type of vehicles (i) at parking spot(j) in on-street parking lot.

$Pa_{i,j}$= Average parking accumulations of each type of vehicles (i) at parking spot (j) in on-street parking lot.

$r_{i,j}$ =Average Arrival rate of each types of vehicles (i) at parking spot (j) in on-street parking lot.

5.3.3 Model Formulation

The model formulation considered the small scale parking service provider from Addis Ketema sub-city. This small scale group provides parking service for three types of vehicles such as Trucks($a_{1,j}$), Passenger cars ($a_{2,j}$), and motorcycle ($a_{3,j}$) and maximum parking capacity is 60 passenger cars in one side of the road.

For the purpose of the LP-model development the vehicles with the parking area utilization of 28.125 m. sq is for truck vehicle($a_{1,j}$), parking area utilization of 12.5 m. sq is for passenger cars($a_{2,j}$), and parking area utilization of 2.47 m. sq is for motorcycles($a_{3,j}$).

The objective of the model is to maximize the total parking area capacity for three types of vehicles. That is maximizing $\sum_{i=1}^{n}\sum_{j=1}^{m}(a_{1,j}+a_{2,j}+a_{3,j})$ by fulfilling different constraints.

The first constraint (is to set the overall combined parking area capacity of the three types of vehicles (i) at parking spot (j)ensures that the sum of the parking area in each parking lot is less than or equal to the total parking area capacity ($A_{i,j}$). Mathematically it is expressed as$\sum_{i=1}^{n}\sum_{j=1}^{m}a_{i,j} \leq A_{i,j}$ (5.1)

1. Proportion of average arrival rate for trucks($a_{1,j}$), passenger cars($a_{2,j}$), and motorcycle ($a_{3,j}$) in the parking lot are the following:-

   $(a_{1,j}+a_{2,j}+a_{3,j})*\left(\frac{r_{1,j}}{r_{1,j+}r_{2,j}+r_{3,j}}\right)$

   $(a_{1,j}+a_{2,j}+a_{3,j})*\left(\frac{r_{2,j}}{r_{1,j+}r_{2,j}+r_{3,j}}\right)$, and

   $(a_{1,j}+a_{2,j}+a_{3,j})*\left(\frac{r_{3,j}}{r_{1,j+}r_{2,j}+r_{3,j}}\right)$

2. Proportion of average parking duration for trucks($a_{1,j}$), passenger cars($a_{2,j}$), and motorcycle ($a_{3,j}$) in the parking lot are the following:-

   $(a_{1,j}+a_{2,j}+a_{3,j})*\left(\frac{Td_{1,j}}{Td_{1,j+}Td_{2,j}+Td_{3,j}}\right)$

   $(a_{1,j}+a_{2,j}+a_{3,j})*\left(\frac{Td_{2,j}}{Td_{1,j+}Td_{2,j}+Td_{3,j}}\right)$, and

$$(a_{1,j} + a_{2,j} + a_{3,j})*\left(\frac{Td_{3,j}}{Td_{1,j+}Td_{2,j}+ Td_{3,j}}\right)$$

3. Proportion of average parking accumulation for trucks($a_{1,j}$), passenger cars($a_{2,j}$), and motorcycle ($a_{3,j}$) in the parking lot are the following:-

$$(a_{1,j} + a_{2,j} + a_{3,j})*\left(\frac{Pa_{1,j}}{Pa_{1,j+}Pa_{2,j}+ Pa_{3,j}}\right)$$

$$(a_{1,j} + a_{2,j} + a_{3,j})*\left(\frac{Pa_{2,j}}{Pa_{1,j+}Pa_{2,j}+ Pa_{3,j}}\right), \text{ and}$$

$$(a_{1,j} + a_{2,j} + a_{3,j})*\left(\frac{Pa_{3,j}}{Pa_{1,j+}Pa_{2,j}+ pa_{3,j}}\right)$$

The other constraints of parking area capacity based on different situation in parking lot such as arrival rate of vehicles, average parking duration, and average parking area accumulations based on vehicles size and parking angle. In this regarded, second(5.2), third(5.3) and fourth (5.4) constraint show that the parking area required for each types vehicles such as truck ($a_{1,j}$), passenger cars ($a_{2,j}$) and motorcycle ($a_{3,j}$) and the proportion of vehicles(i) average arrival rate ($r_{i,j}$),average parking accumulation($P_{i,j}$) , and average parking duration$\left(Td_{i,j}\right)$ for every 15 minutes for each types of vehicles(i)in the parking lot. Mathematically they are expressed as:

$$\sum_{i=1}^{n}\sum_{j=1}^{m} a_{i,j}\left(\frac{r_{i,j}}{\sum_{i=1}^{n}\sum_{j=1}^{m} r_{i,j}}\right) \leq a_{i,j} (5.2)$$

In the model constraint, in Equation (5.2) ensure that the proportion of vehicles average arrival rate every 15 minutes for each types of vehicles computed from the average arrival rate divided by total average arrival rate for three types of vehicles (i) and the multiplied by parking space capacity is less than or equal to the total parking space.

$$\sum_{i=1}^{n}\sum_{j=1}^{m} a_{i,j}\left(\frac{Td_{i,j}}{\sum_{i=1}^{n}\sum_{j=1}^{m} Td_{i,j}}\right) \leq a_{i,j} (5.3)$$

In the model constraint, in Equation (5.3) reflect that the proportion of vehicles average parking duration every 15 minutes for each types of vehicles(i) computed from the average parking duration divided by total average parking duration for three types of vehicles (i) and then multiplied by parking space capacity is less than or equal to the total parking space for vehicle (i).

In the model constraint, in Equation (5.4) ensure that the proportion of vehicles average parking accumulation every 15 minutes for each types of vehicles computed from the average parking accumulation divided by total average parking accumulation for three types of vehicles (i) and the multiplied by parking space capacity is less than or equal to the total parking space for vehicle(i).

$$\sum_{i=1}^{n}\sum_{j=1}^{m} a_{i,j}\left(\frac{Pa_{i,j}}{\sum_{i=1}^{n}\sum_{j=1}^{m} Pa_{i,j}}\right) \leq a_{i,j} (5.4)$$

The non-negativity in Equation (5.6) keeps the variables equal to or greaterthan zero.

$$a_{i,j,r_{i,j},Td_{i,j},Pa_{i,j}\geq 0} (5.6)$$

The constraints equations (5.1), (5.3), (5.4), and (5.5) were formulated in (Said Munzir et al, 2010) models. But in this study model, added additional constraint which is Equation (5.2) for optimization of parking spaces in the on-street parking lot. Equation (5.2) is called the average arrival rate constraint of vehicles in the parking lot this equation (5.2) included additional three sub constraints which are constrain of Trucks (a_1), constrain of Passenger cars (a_2) and constraint of motorcycles (a_3).

The general LP-model that determine the optimal parking space by reducing parking area and parking addition numbers of vehicles at the existing parking lot is therefore formulated as follow:

Objective function:

$$\text{Maximize } \sum_{i=1}^{n}\sum_{j=1}^{m}(a_{1,j} + a_{2,j} + a_{3,j})$$

Subject to:

Constraint of total parking capacity

$$C_x a_{1,j} + C_y a_{2,j} + C_z a_{3,j} \leq A_{i,j}$$

Constrain of arrival rate ($r_{i,j}$)

$$(a_{1,j} + a_{2,j} + a_{3,j}) * \left(\frac{r_{1,j}}{\sum_{i=1}^{n}\sum_{j=1}^{m}(r_{1,j} + r_{2,j} + r_{3,j})}\right) \leq a_{1,j}$$

$$(a_{1,j} + a_{2,j} + a_{3,j}) * \left(\frac{r_{2,j}}{\sum_{i=1}^{n}\sum_{j=1}^{m}(r_{1,j} + r_{2,j} + r_{3,j})}\right) \leq a_{2,j}$$

$$(a_{1,j} + a_{2,j} + a_{3,j}) * \left(\frac{r3_{,j}}{\sum_{i=1}^{n}\sum_{j=1}^{m}(r_{1,j} + r_{2,j} + r_{3,j})}\right) \leq a_{3,j}$$

Constraint of parking Duration ($Td_{i,j}$)

$$(a_{1,j} + a_{2,j} + a_{3,j}) * \left(\frac{Td_{1,j}}{\sum_{i=1}^{n}\sum_{j=1}^{m}(Td_{1,j} + Td_{2,j} + Td_{3,j})}\right) \leq a_{1,j}$$

$$(a_{1,j} + a_{2,j} + a_{3,j}) * \left(\frac{Td_{1,j}}{\sum_{i=1}^{n}\sum_{j=1}^{m}(Td_{1,j} + Td_{2,j} + Td_{3,j})}\right) \leq a_{2,j}$$

$$(a_{1,j} + a_{2,j} + a_{3,j}) * \left(\frac{Td_{3,j}}{\sum_{i=1}^{n}\sum_{j=1}^{m}(Td_{1,j} + Td_{2,j} + Td_{3,j})}\right) \leq a_{3,j}$$

Constraint of parking accumulation($Pa_{i,j}$)

$$(a_{1,j} + a_{2,j} + a_{3,j}) * \left(\frac{Pa_{1,j}}{\sum_{i=1}^{n}\sum_{j=1}^{m}(Pa_{1,j} + Pa_{2,j} + Pa_{3,j})}\right) \leq a_{1,j}$$

$$(a_{1,j} + a_{2,j} + a_{3,j}) * \left(\frac{Pa_{2,j}}{\sum_{i=1}^{n}\sum_{j=1}^{m}(Pa_{1,j} + Pa_{2,j} + Pa_{3,j})}\right) \leq a_{2,j}$$

$$(a_{1,j} + a_{2,j} + a_{3,j}) * \left(\frac{Pa_{3,j}}{\sum_{i=1}^{n}\sum_{j=1}^{m}(Pa_{1,j} + Pa_{2,j} + Pa_{3,j})}\right) \leq a_{3,j}$$

$$a_{i,j}, r_{i,j}, Td_{i,j}, P_{ai,j} \geq 0$$

Table 13: standard table of vehicle dimensions

No	Parking angle of vehicles	standard Formulas to calculate the road lengths	Existing parking capacity of vehicle type for passenger cars ($a_{2,j}$)	Parking Lot Length
1	Parallel parking	$l = 5.9N$	60	350
2	30°	$l = 5.58 +$ (N-1)*5	60	300.58
3	45°	$l = 3.54N + 1.77$	60	214.17
4	60°	$l = 2.89N + 2.16$	60	175.56
5	90°	$l = 2.5N$	55	150

Table 14: Calculation of vehicles parking area based on parking lot capacity.

			Types of vehicles and their width			Parking area for each types of vehicles in (m. sq)		
No	Parking angle	Parking lot length	Truck parking width	cars parking width	motorcycle parking width	Truck parking area($a_{1,j}$)	Cars parking area($a_{2,j}$)	Motor cycle parking area($a_{3,j}$)
1	Parallel parking	350	3.75	2.5	1.3	1312.50	875	455.00
2	30°	300.58	3.75	2.5	1.3	1127.18	751.45	390.75
3	45°	214.17	3.75	2.5	1.3	803.14	535.425	278.42
4	60°	175.56	3.75	2.5	1.3	658.35	438.9	228.23
5	90°	150	3.75	2.5	1.3	562.50	375	195.00

5.3.4 Parking area Factors Analysis

The following parking area factors analysis calculation based on the survey data from the Appendix-C.

Parking Lot Accumulation : Parking lot accumulation calculated based on the survey data for a 15 minute interval is the total of number of vehicles(i) in the place for that time interval in the parking lot(j)is sum vertical the same day arrival rate of vehicles in the parking lot. For instance in appendix-C the Monday Accumulation for first time interval for 15 minutes for the first Day = 44 vehicles

Parking Duration: the Parking duration calculated by considering both sides parking lot accumulation capacity=120 parking spot available. It can be calculated as sum of the accumulation for each time interval * time interval divided by the parking volume.

$$\text{Parking duration} = \frac{\text{sum of the accumulation arrival rate of vehicles(i)} * \text{time interval}}{\text{total parking capacity in both sides(j)}}$$

Parking Load: the parking load is calculated by summing the each type of vehicles (i) arrived in the time interval of 15 minutes and multiplied by the time interval 15 minutes and divided by 60 minutes.

Parkingload

$$\frac{(\text{sum of arrival rate of vehicles (i)in 15 minutes time interval}) * \text{time interval 15 minute}}{\text{60 minute}}$$

Average hourly Parking capacity = the parking capacity of vehicles (i) multiplied with number of hours in the parking lot.

Occupancy of Parking Lot: Occupancy allows determining whether or not you have enough parking spaces. Occupancies of (85-90%) or just below are ideal the demand is being met without waste**.** Occupancy for that time interval is accumulation in that particular interval divided by total number of bays.

Average Parking Duration: Average parking duration determined by the average arrival rate of vehicles (i) per hour divided by total available number of bay.

$$\text{Average parking duration} = \frac{\text{average arrival rate of vehicles(i)per hour}}{\text{total availble numbers of bays}}$$

Parking Turnover: Parking turnover determined by the total arrival rate of vehicles (i) is divided by the maximum arrival numbers of vehicle (i).

$$\text{parking Turnover} = \frac{\text{total arrival rate of vehicles per hour(i)}}{\text{maximum number of vehicles arrive(i)at the parking lot(j)}}$$

Parking Index: Parking index determined by the total parking load divided by maximum arrival rate of vehicles (i) multiplied by total service time

$$\text{ParkingIndex} = \frac{\text{parkingload} * 100}{\text{maximumarrivalrateofvehicle(i)} * 2\text{hr}}$$

Table 15: The parking lot demand per day and maximum daily arrival rate of vehicles

No	Parking Days	Demand Per Day	Maximum daily arrival rate of vehicles (i)
1	Monday	389	64
2	Tuesday	403	80
3	Wednesday	413	77
4	Thursday	416	78
5	Friday	416	78
6	Saturday	449	90
7	Sunday	263	46
average daily demand		**392.7**	

Total parking demand per day=average amount of cars parked in the place =393 vehicles per day.

Table 16: Summary of the parking area factors in the parking lot form table 23 and survey data in Appendix-C.

No	Maximum daily arrival of vehicles	average hourly parking capacity	Parking loads of vehicles per hours	average parking duration (minutes)	Arrival rate of vehicles per hour
	40	60	10	10	20
1	64	60	16	16	32
2	80	60	20	20	40
3	77	60	19.25	19.25	39
4	78	60	19.5	19.5	39
5	78	60	19.5	19.5	39
6	**90**	**60**	**22.5**	**22.5**	**45**
7	46	60	11.5	11.5	23

The above the average parking duration for each type vehicles such as trucks, passenger cars and motorcycles calculated based on the survey data from the appendix-C.

Table 17: arrival rate of vehicles

arrival rates of vehicles (i) at the parking lot			proportion of arrival rate of ($r_{i,j}$) for each types of vehicles(i)			proportion parking accumulation($Pa_{i,j}$) for each types of vehicles(i)		
$r_{1,j}$	$r_{2,j}$	$r_{3,j}$	trucks ($r_{1,j}$)	passenger cars($r_{2,j}$)	motorcycle ($r_{3,j}$)	trucks ($Pa_{1,j}$)	passenger cars($Pa_{2,j}$)	motorcycle ($Pa_{3,j}$)
8	52	2	0.125	0.8	0.03	0.5	0.33	0.2
18	62	0	0.2	0.7	0	0.5	0.33	0.2
6	67	4	0.07	0.87	0.005	0.5	0.33	0.2
10	68	0	0.12	0.87	0	0.5	0.33	0.2
10	68	0	0.12	0.87	0	0.5	0.33	0.2
8	30	2	0.2	0.75	0.05	0.5	0.33	0.2

5.3.5 Input Parameters to the Model

To solve the LP-model, the input parameters, which are involved in the model, are need to be determined first. These parameters are either computed or obtained from the secondary data. The sample input parametric value on-street parking is taken from the survey data from the appendix-C are presented in table, 22, 23 and 24.after substituting the value of input parameters and constants into the LP model, it can be re-written as

Maximize $\sum_{i=1}^{n}\sum_{j=1}^{m}(a_{1,j}+a_{2,j}+a_{3,j})$

Subject to

$$28.125a_{1,j}+12.5a_{2,j}+2.47a_{3,j} \leq 2642.5$$

$$(a_{1,j}+a_{2,j}+a_{3,j}) * (\frac{r_{1,j}}{\sum_{i=1}^{3}\sum_{j=1}^{60}(r_{1,j}+r_{2,j}+r_{3,j})}) \leq 1312.5$$

$$(a_{1,j}+a_{2,j}+a_{3,j}) * (\frac{r_{2,j}}{\sum_{i=1}^{3}\sum_{j=1}^{60}(r_{1,j}+r_{2,j}+r_{3,j})}) \leq 875$$

$$(a_{1,j}+a_{2,j}+a_{3,j}) * (\frac{r3_{,j}}{\sum_{i=1}^{3}\sum_{j=1}^{60}(r_{1,j}+r_{2,j}+r_{3,j})}) \leq 455$$

$$(a_{1,j}+a_{2,j}+a_{3,j}) * (\frac{Td_{1,j}}{\sum_{i=1}^{3}\sum_{j=1}^{60}(Td_{1,j}+Td_{2,j}+Td_{3,j})}) \leq 1312.5$$

$$(a_{1,j}+a_{2,j}+a_{3,j}) * (\frac{Td_{1,j}}{\sum_{i=1}^{3}\sum_{j=1}^{60}(Td_{1,j}+Td_{2,j}+Td_{3,j})}) \leq 875$$

$$(a_{1,j}+a_{2,j}+a_{3,j}) * (\frac{Td_{3,j}}{\sum_{i=1}^{3}\sum_{j=1}^{60}(Td_{1,j}+Td_{2,j}+Td_{3,j})}) \leq 45$$

$$(a_{1,j}+a_{2,j}+a_{3,j}) * (\frac{Pa_{1,j}}{\sum_{i=1}^{3}\sum_{j=1}^{60}(Pa_{1,j}+Pa_{2,j}+Pa_{3,j})}) \leq 1312.5$$

$$(a_{1,j}+a_{2,j}+a_{3,j}) * (\frac{Pa_{2,j}}{\sum_{i=1}^{3}\sum_{j=1}^{60}(Pa_{1,j}+Pa_{2,j}+Pa_{3,j})}) \leq 875$$

$$(a_{1,j}+a_{2,j}+a_{3,j}) * (\frac{Pa_{3,j}}{\sum_{i=1}^{3}\sum_{j=1}^{60}(Pa_{1,j}+Pa_{2,j}+Pa_{3,j})}) \leq 455$$

$a_{i,j}, r_{i,j}, Td_{i,j}, P_{ai,j} \geq 0$ and solved by Lingo software and the result attached in the appendix-B.

CHAPTER-SIX

6.1 optimization and validation

6.1.1 Introduction

This study considering parking space as case study because as in study investigation in chapter three from questionnaire ,interview and field survey of the data finding of parking space is difficult situation for drivers in Addis Ababa city. So that parking space optimization model used to minimize parking problems by developing LP model. The LP model objective is to maximize the existing on-street parking capacity by considering different constraints such as road length and width, parking angles, average parking duration, average arrival rate of vehicles, vehicles size, and average accumulation capacity and considering different assumptions.

Scenario-1: considering average daily arrival rate and average parking duration of vehicles.

The Scenario considered average daily arriving rate and average parking duration of vehicles in the parking lot, the @PEL Function determines the fraction of customers lost due to all parking spots being busy in the parking lot. In the model by use @PEL to solve for the number of parking spots in the parking lot that limit customer loss (P= 5%).

```
MODEL:
! Arrival rate (AR) of vehicles per hour;
AR = 20;
! Average parking duration (APD) per vehicles in the parking lot with minutes;
APD = 16;
! Parking time per drivers in hours (STH);
STH = APD/ 60;
! Fraction customers finding all parking spots busy;
FP = .05;
! The PEL function finds number of parking spots (PS) needed in the parking lot, PS;
FP = @PEL (AR * APD, PS);
END
```

In this scenario considered average daily maximum arrival rate of vehicles in the parking lot, average parking duration, and without considering vehicles size effects on the parking lot capacity, and result delivered after solving with LINGO 17software.The value of average daily maximum arrival rate and average parking duration taken from statically parking calculation based on on-street parking survey from appendix-C and the result are based on scenario are**220** parking spot.

The result shows that the maximum needed parking spot are 220 and the existing parking lot capacity is 60 vehicles only. So that 160 cars or 62.5 % are can't found parking space. As result, the drivers search another parking lot, waiting or parking illegally this situation creates congestion on the roads and difficult to traffic flow. When considered average daily arrival rate of cars and average parking duration and based on the survey data average daily arrival rate and average parking duration are 20 vehicles per hour and 16 minutes respectively.

Scenario-2: average daily maximum arrival rate and average parking duration of vehicles.

The scenario Considered average daily maximum arrival rate and average parking duration of vehicles in the parking lot, the @PEL Function determines the fraction of customers lost due to all parking spots being busy in the parking lot. In the model by use @PEL to solve for the number of parking spots in the parking lot that limit customer loss (P= 5%).

```
MODEL:
! Arrival rate (AR) of vehicles per hour;
AR = 45;
! Average parking duration (APD) per vehicles in the parking lot with minutes;
APD = 24.5;
! Parking time per drivers in hours (STH);
STH = APD/ 60;
! Fraction customers finding all parking spots busy;
FP = .05;
! The PEL function finds number of parking spots (SP) needed in the parking lot, PS;
FP = @PEL (AR * APD, PS);
END
```

In scenario-2 considered average daily maximum arrival rate of vehicles in the parking lot, average parking duration, and without considering vehicles size effects on the parking lot capacity, and result delivered after solving with LINGO 17software.The value of average arrival rate and average parking duration taken from appendix-C and the result are based on scenario are**1062** parking spot.

The result shows that the maximum needed parking spot are 1062 and the parking lot capacity is 60 vehicles only. So that 1002passenger cars or 94.35 % are can't found parking space this creates huge problem in the city. As result, the drivers search another parking lot, waiting or parking illegally this situation creates congestion on the roads and difficult to traffic flow. When considered average daily arrival rate of cars and average parking duration and based on the survey data average daily arrival rate and average parking duration are 45 vehicles per hour and 24.5 minutes respectively.

Case-1: without considering parking angle

In this case considering vehicles parking lot parking capacity, considering the same vehicle size in each constrain of the model, considering the same average arrival rate, considering the same average parking duration, considering different parking area respectively with vehicles size and without any parking angle the following result delivered after solving with LINGO 17 software are Objective value=**10,570.00**

Case-2: considering parking angles

In this case by considering vehicles parking lot parking capacity, considering the same size vehicles in each constrain of the model, considering the same average arrival rate, considering the same average parking duration and considering parking angle with **30°** in the parking lot and the following result delivered after solving with LINGO 17 software is Objective value=**9077.520**.Therefore, other solutions of parking areas are 6467.94, 5301.92 and 4530 meter square from 45, 60 and 90 degree parking angles respectively from appendix-B.

6.2 summary of the result

The model is formulated as mathematical linear programming to save parking space and the model is solved with LINO 17 software and the solution presented in tablebelow.

Table 18: summary of Result

				Saved Parking Area form Angle parking		
No	Parking Angles	Total Parking Area (meters. sq) or objective value	Saved Parking Area(meters. sq)	Truck Parking Area($a_{1,j}$)	Cars Parking Area($a_{2,j}$)	Motorcycle Parking Area($a_{3,j}$)
1	Parallel parking	10,570	0	0	0	0
2	30 degree parking	9077.520	1492.48	53	119	4279
3	45 degree parking	6467.94	4102.06	146	328	1667
4	60 degree parking	5301.92	5268.08	187	421	2133
5	90 degree parking	4530	6040	215	483	2445

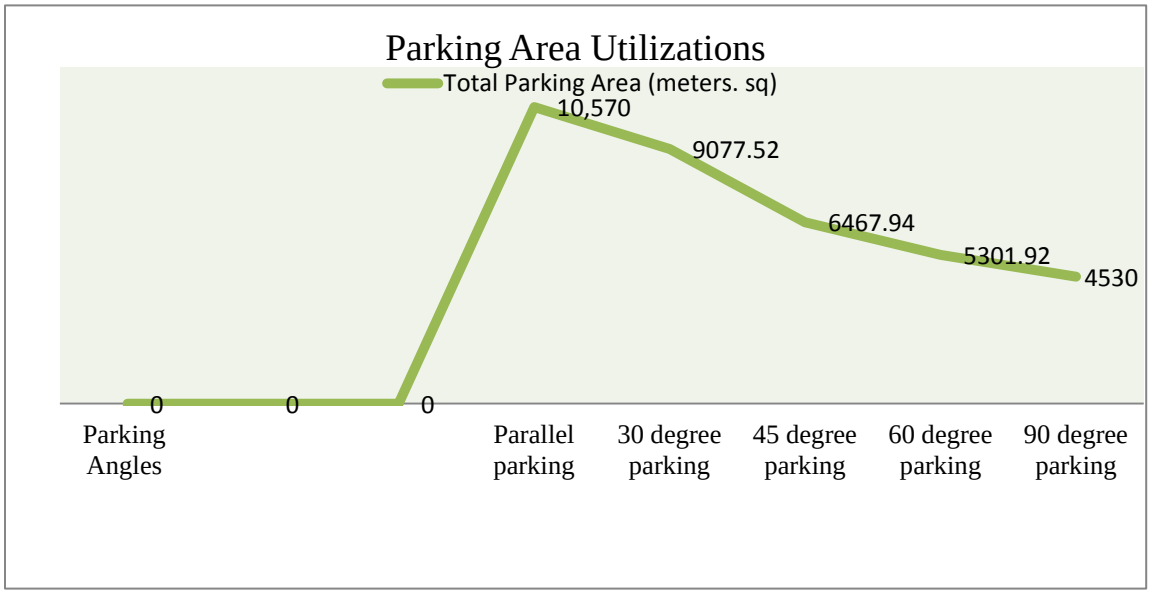


Figure 15: Parking Area Utilizations

6.3 Comparison of improved parking capacity

The existing parking capacity and improved is compared in the following table.

Table 19: comparison of improved parking capacity

No	Parking angles	Existing parking capacity	Improved parking capacity	Decision variable	Reduced cost
1	parallel parking	60	0	A1	29.985
				A2	14.360
				A3	4.330
2	30° parking	60	119	A1	30.155
				A2	15.980
				A3	9.284
3	45°parking	60	328	A1	30.030
				A2	15.980
				A3	9.284
4	60° parking	60	421	A1	30.155
				A2	14.530
				A3	4.500
5	90° parking	60	483	A1	30.155
				A2	15.980
				A3	9.284

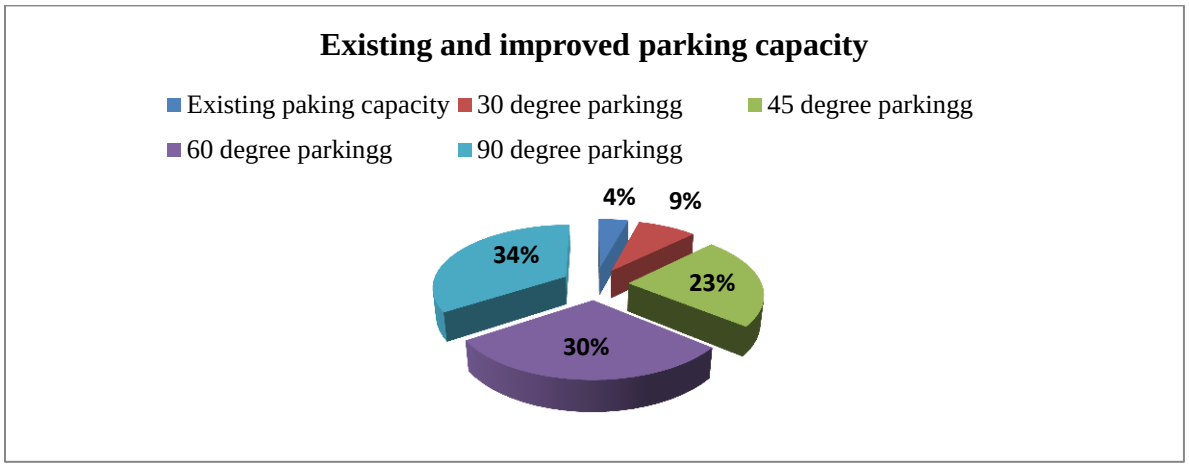


Figure 16: Existing and improved parking capacity

The result show that maximum parking area saved is **6040** meter squares from 90 degree parking angle compared with existing parking capacity. And other saved parking areas are 1492.48 from 30 degree parking, 4102.06 from 45 degree parking and 5268.08 meter square from 60 degree parking angle. In the above LINGO 17 software analysisthe90 degree parking saved maximum parking area. In another hand direction, they reduced road width or diameters. For instance, 20meter width roads reduced to 15 meter width for passengers cars type and from 20meter road diameters reduced to 12.5meter for trucks type vehicles and which are not recommended for one direction way and creates congestion on the roads and it's difficult to move vehicles freely on the roads. So that it's not generally recommended to on-street angle parking.

Therefore ,60 degree parking area recommended for angle parking because they saved maximum parking area compared with 30,and 45 degree of parking and reduced maximum decision variable(trucks A1,passenger cars A2,and A3 for bicycles) cost and it's recommended for one direction way and it's comfortable for the drivers for easily entry and exit from parking lot.

6.3 Model Evaluation and Validation

In this section the output of the model for both are without considering parking angle, and considering parking angle case is analyzed to see the improvements that can be found in the parking facilities. The parameters used for comparing and evaluation of the model are improved number of parking spot, increase parking space, decrease congestion, total searching time of parking spot, and . The model developed for calculating the optimal parking space by considering different constraints such as arrival rate of vehicles, vehicles size effects on the parking area and parking angle effects on the parking angle and optimization LP model are solved with LINDO software and the details of the solution procedure are also presented in above.

6.3.1 Model Result Evaluation

The Lingo software final result without considering parking angle is **10,570** m .sq parking area used to park various vehicles such as trucks, passengers cars and motorcycles.

As explained in model development part, the actual parking capacity determined by considering parking area for each type vehicle(i) in the parking aspot(j) in the parking lots can be calculated as follows:-

Parking area of vehicles=parking*road stall

Existing parking area=10,570 m. sq. This shows that the existing parking capacity is 60 vehicles in on side of the road. The following calculation shows the addition saved parking area compared to existing parking lot. For instance, 30 degree parking angle saved parking area calculated as:-

$$\text{A parking area for each types of vehicles (i)in parking spot (j)} = \frac{\text{saved parking area } (a_{i,j})}{\text{parking area utilization}(C_x)}$$

As the similar procures to determine the saved parking area for the two types of vehicles (i) which are passenger cars and motorcycles are summarized in the table 28:

Table 20: Model result evaluations

No	Parking angle	Existing parking capacity	Improved Number of parking spot
1	Parallel parking	60	0
2	30degree parking	60	119
3	45 degree parking	60	328
4	60 degree parking	60	421
5	90 degree parking	60	483

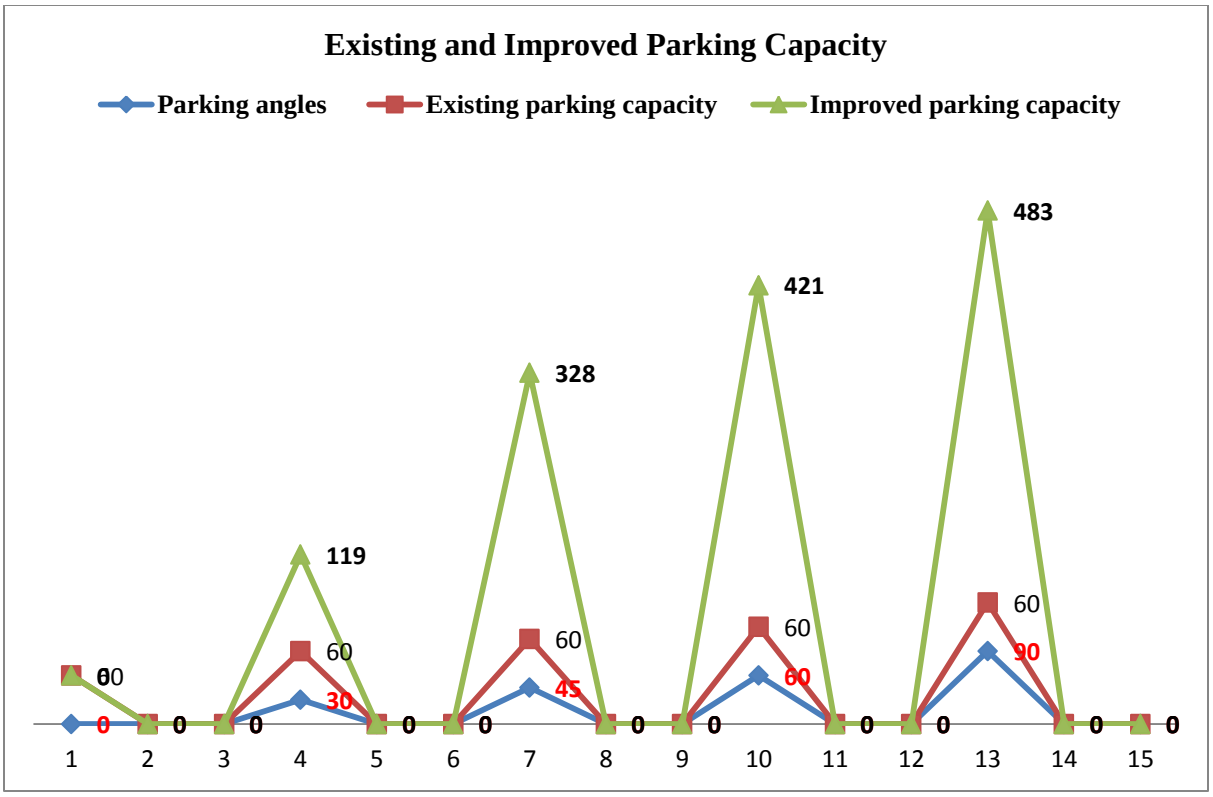


Figure 17: Existing and Improved parking capacity

6.4 Sensitivity Analysis

Developing the problem as linear programming and found solution by considering main parameters for the situation. And the final step of decision makers may have used checking subjective estimates for certain parameters. The parameters are considered by changing coefficient of constraints, changing coefficient of objective function and the right-hand-side constraints value change in the LP model. If the optimal solution is relatively insensitive to reasonable change and it is confident to implementing the solutions. But, if the optimal solution is sensitive to change and it need precise estimation of those parameters.

6.4.1Sensitivity analysis of Right Hand Side

Considering the RHS of the first constraints which is parking space of vehicles (trucks, cars and bicycles) is increased by 1 and new optimal solution is obtain and described in below table.

6.4.2 Sensitivity analysis of changing coefficients of constraints

Considering the coefficients of constraints which are proportion of vehicles average arrival rate, average parking accumulation and average parking duration for each type of vehicles values increased by 1and the new optimal solution obtained and described in below table.

Table 21: Comparison of Sensitivity Analysis result

No	Parking Angles	Optimal Solution	After sensitivity analysis	
			changing right hand side(meters. sq)	changing coefficients of constraints
1	parallel parking	10,570	10571.00	10,569.000
2	30 degree parking	9077.520	9077.530	9076.520
3	45 degree parking	6467.94	6468.940	6465.940
4	60 degree parking	5301.92	5302.920	5300.920
5	90 degree parking	4530	4531.000	4529.000

In sensitivity analysis, the result shows that there are some changes when considering right hand side and changing the value of constraints in the model. The changes indicate that when we increase the parking area directly increase parking capacity of the vehicles in the parking lot and when increase the average arrival rate and parking duration indirectly decrease parking capacity of parking lot.

CHAPTER-SEVEN

7.1 Conclusion and Recommendation

7.1.1Conclusion

Currently in Addis Ababa city there are so many problems which are mainly concerned with shortage of parking space are such as traffic congestion on the roads, due to searching of parking space emission of CO_2 to the environment and waiting for long time to find parking spot. In this study current parking situation of city has been analyzed and allocating optimal parking location based on locally and international parking site selection criteria with the help of AHP methods and mathematical LP- model to maximize parking capacity performance for Addis Ketema sub-city. The data used in this thesis has been collected from the parking lot supervisors, drivers and the responsible bodies in the government with questionnaires, interviews and also the survey data were conducted to know the arrival rate of vehicles, parking capacity and parking duration of vehicles in the parking lot.

In this study two scenarios have been used to which are average daily arrival rate of vehicles and average parking duration and average daily maximum arrival of vehicles and average parking duration to minimize as well as solving space problems in Addis Ababa Sub cities so that the LP model has been developed and tested by considering such parameters. In this two scenarios there are customers who are not satisfied with the service and 165 parking spot or 75% customers couldn't find parking area in the 1st scenario and in the 2nd scenario1002 parking spot or 95% of customers couldn't find the parking space, which indicate the demands of additional parking area in city that is why I have developed the model by using the above scenarios such that existing parking capacity performance is used as a basis.

As result of mathematical linear programming model and Lingo software shows the result of improvement of angle parking and the existing parking capacity increased by 1492.48, 4102.06, 5268.08 and 6042 meter square from parking angle such as 30°, 45°, 60°, and 90°respectively. The existing parking capacity is parked 60 vehicles only and the existing parking lot needed additional parking spots which are 160 from sceniaro-1 and 1002 from scenario-2 to fulfill the drivers. As the result of linear programming model the existing

parking capacity increased by 119, 328, 421, and 483 parking spot and scenario- one is fulfilled with 45, 60, and 90 degree parking angles and considering scenarios-two existing parking capacity increased by 11.2%, 31%, 40% and 45.4% with respectively parking angles.

7.1.2 Recommendation

Based on the analysis found from the current parking system of Addis Ababa and the solution are proposed to minimizing parking space problems in the city and the following points are recommended to bring a significant improvement for the parking service of Addis Ababa city.

- Parking site selection should be based on the international parking site selection criteria to reduce parking lot searching time, walking distance to final destination, and to minimize congestion on the roads. The current Addis Ababa parking site location criteria based on the commercial centers, highest pedestrian movement area and land situation of the site.
- In Addis Ababa the shortage parking space is known. So that the city administration should be taken another measurement introduced parking strategy and police such as centralized parking system to reduced congestion and on-street parking, Metric parking system this system introduced price based system and increase parking price in the peak-time, and shuttle parking system this system they have combination with central parking system. The shuttle system introduced shuttle buses to reach final specific location from central parking location….etc.
- The mathematical LP models can be used any time to determine the optimal parking area based on the parking angles, arrival rate of vehicles, parking capacity and average parking duration. In this study the arrival rate of vehicles and parking duration for a given time period is recoded and known. But, the parking micro-enterprise has not recorded the vehicles arrival and parking duration daily.
- As recommendation to the enterprise they should be at least recorded on an hourly basis. Because to now the parking capacity of their parking lot and to pick out the maximum arrival time and to adjust situation.

7.1.3 Future Research Direction

In the above chapters discussed about parking system and conducted related different articles and investigated some gaps related of parking system. Therefore, the gaps are summarized and can be given to the direction for the future studies in the below:

- The recommended future research areas are information availability effects on the drivers and introduce technology such as e-business, internet, and mobile application for the purpose of information availability by internet and mobile application for the seeking of accessibilities of parking space, to reduce searching time to find free parking space and for easily payment.

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Appendix-A

Addis Ababa University Institute of Technology

School of Mechanical and Industrial Engineering

(Postgraduate Program in Industrial Engineering)

Dear respondent, thank you in advance for your unreserved cooperation.

This questionnaire is designed to gather data for research purpose for the fulfillment of a MSC in the title of "**Analysis and Optimization of Car Parking Space for Addis Ababa city"** for Addis Ababa car parking system. Accordingly, your genuine responses are extremely important for the purpose of this research and result is used for **research purpose only**. Hence, you are kindly requested to feel free and respond all questions.

Part-I: Interview Questions (Responsible Bodies)

No	Interview Questions
1	What are the main parking area selection criteria in Addis Ababa City?
2	What types of strategy and policy provide to solve the current parking practice in Addis Ababa? Would you please describe how Addis Ababa city implement them?
3	Would you please tell me the car parking area shortage effects on traffic flow in Addis Ababa?
4	Are there enough car parking places in Addis Ababa? If No, What are the main causes of shortage?
5	Which parking locations are appropriate for the parking site and why?
6	How can be improved the service of parking in Addis Ababa?

Please ranking by using liker scale based on your profession skills (1= very low, 2=low, 3=moderate, 4=high, 5= very high) the following parking area factors comparing with our country criteria. The parking area factors are taken from the developed country parking area and selection criteria.

The Parking site selection criteria and weight (Shiferaw, 2014).

Car parking area selection Factors(consideration criteria)	**% of weight**	Locations									
		A. ketama	Bole	gullele	Ledeta	Nifasike	kolfe	yeka	Arada	Akaki	kirkos
Road, rails or bus links	16										
Staff parking	15										
Parking Lease or rent costs	15										
Proximity to market or client	12										
Customer or visitor parking	11										
Proximity to labor supply	11										
Rail or bus links	6										
Proximity to goods or services	5										
Traffic noise	3										
Proximity to competitors	3										
Air quality	3										

Part II: Distributed Questionnaires (Drivers)

Please put a tick mark (n) in the box provided

1) Are you owner of the vehicle?
   a) Yes ☐ b) No ☐
2) Job
   a) Private b) Business c)worker e)other
   - ❖ Please specify, If you select other _____

Part -1: The purpose of the following questionnaires is to assess the current parking behavior and your views and opinions about the present situation of car parking system in Addis Ababa. Therefore, please answer carefully for each question.

1. Would you use parking? The answer is yes
   a) Always b) sometimes c)never
2. What type of parking always you should select?

   a) on-street parking b) off- street parking c) garage parking d) smart parking centers

3. If you answer Q2 what is your reason to select this parking type?

_____

4. How often you are coming to this parking lot?
   a) Daily b)Weekly c)Monthly

5. Are you finding parking facility nearest to your final destination in Addis Ababa city?
   A) Yes b) No
6. What is your measurement if not have available spot in parking center?
   a) waiting b)illegal parking c) searching another parking d) back to home e)elsewhere (mall, shopping centered)
7. If you answer for Q6 is searching how long you search?

_____

8. If you answer for Q6 is waiting how long you stay?

_____

9. What are major car parking facility unavailability effects on traffic flow in Addis Ababa?

_____

_____

_____

10. What is expected walking time to your final destination from parking lot?

_____

11. What is expected walking distance to your final destination from parking lot?

_____

12. What is your accepted parking price for you?

_____

13. What are your most priority criteria on the car parking lot? Please, put (X) symbol on box.

Free space availability	Security and safety	walking time to final destination	walking distance to final destination	parking price	Nearest to roads and markets	Others

14. If you select for Q13 is other ,please specify

_____

15. Searching of parking lot (spot) in Addis Ababa city creates congestion on traffic flow?

Yes	No

16. The unavailability of parking lot creates congestion on the roads?

) Yes b) No

17. What are the most important problem that facing parking in Addis Ababa city?

_____

_____

_____

18. Final, what are your final suggestions to improve parking service for Addis Ababa city?

_____

_____

_____

Addis Ababa University Institute of Technology

School of Mechanical and Industrial Engineering

(Graduating program in Industrial Engineering)

ይህመጠይቅየተዘጋጀውለድህረምረቃ (MSC) መመረቂያፅሁፍ (Parking Analysis and optimization) በሚልርዕሥላይነዉ፡

I. **personal information (የግልመረጃ)**

ከተሰጡትአማራጮችመካከልበሚሥማሙትላይየ''✓'' ምልክትያስቀምጡ፡፡

1. የተሸከርካሪባለቤትኖት ?

አዎአይደለም ☐ ☐

2. የሥራዘርፍት ?

የግልበንግድ☐ ☐ ☐ ☐ቀጣሪሌላ

❖ ሌላየሚለውንከመረጡእባኮትንየሥራውንዓይነትይግለፁ ——————————

II. ከሥርየተጠቀሱትጥያቄዎችአላማበአሁንሰዓትእየተተገበረባለውየመኪናማቆሚያ (parking)

ሥርዓትናአተገባበርዙሪያየቀረቡትጥያቄዎችላይየእርሶንሀሳብናአስተያየትበጥንቃቄይምረጡ፡፡

1. ፓርኪንግይጠቀማሉ ?

አዎን ☐ አልጠቀምም ☐

መልሶትንአዎንከሆነ

ሁልጊዜ ☐ አንዳንዴ ☐ አልጠቀምም ☐

መልሶትአልጠቀምምከሆነለምን ?

_____

_____

_____

2. ምንአይነትፓርኪንግይጠቀማሉ ?

A. የመንገድዳርፓርኪንጎች

B. ከመንገድዳርውጪበተሰሩፓርኪንጎች

C. ህንፃላይበተሰሩፓርኪንጎች

3. ለጥያቄሁለትለመረጡትመልስምክንያቱንይግለፁ ?

---

4. ከዚህየፓርኪንግቦታለመጠቀምበምንያህልጊዜይመጣሉ?

ሀ. ሁልጊዜለ. በየሳምንቱሐ. በየወሩ

5. ምንያህልሰዓትይቆያሉበፓርኪንግቦታላይ፡፡

---

6. በእርስየመዳረሻቦታዎችላይበቅርብየፓርኪንግቦታዎችንያገኛሉ?

ሀ. አዎ ☐ አይደለም ☐

7. በፓርኪንግቦታዎችላይበቂየመኪናማቆሚያቦታባይኖሩምንያረጋሉ ?

ሀ. እጠብቃለሁለ. በተከለከለቦታአቆማለሁ

ሐ. ሌላየመኪናማቆሚያእፈልጋለሁመ. ወደቤትእመለሳለሁሰ) ደርቤአቆማለሁ

8. ለጥያቄ 7 መልሶትሌላየመኪናማቆሚያእፈልጋለሁከሆነለስንትሰዓትይፈልጋሉ ? ---

9. ለጥያቄ 7 መልሶትእጠብቃለሁከሆነለስንትሰዓትይጠብቃሉ ?

---

10. መኪናዎችንፓርክካረጉትቦታወደእርሶወዳረሻለመድረስምንያህል**ጊዜ**ቢወስድቦትጥሩነውየሚሉትንጊዜይጥቀሱ ---

---

11. መኪናዎትንፓርክካደረጉበትቦታወደእርሶመዳረሻለመድረስምንያህል**ርቀት**ቢወስድቦትጥሩነውይላሉ ? ---

---

12. ለተጠቀሙበትየፓርኪንግአገልግሎትምንያህል**ክፍያ**ቢከፍሉይመርጣሉ?

---

13. በፓርኪንግመጠቀሚያ**ቦታዎችላይቅድሚያየሚሠጡት**ነገርምንድነው?

ሀ. የክፍትቦታዎችመኖርለ. ደህንነትናጥበቃሐ. ወደመዳረሻየሚፈጅውን**ጊዜ**

መ. ወደየመዳረሻየሚወስደው**ርቀት**ሠ. ዋጋረ. ሌላ ---

14. የፓርኪንግቦታዎችያለመኖርበመንገዶችላይመጨናነቅይፈጠራልብሎያስባሉ?

ሀ. አዎ ☐ ለ. ☐ አይደለም

15. በአ.አከተማውስጥየፓርኪንግቦታያለመኖርበትራፊክፋሰቱላይየሚያስከትለውንችግርጥቀሱ ---

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16. በስተመጨረሻየእርሶሀሳብበአ.አየፓርኪንግአገልግሎትንለማሻሻልምንመደረግአለበትይላሉ፡፡እርሶንሀሳብይጥቀሱ

Appendix-B

Model:

```
Max=1*a1+1*a2+1*a3+S1+1*S2+S3+S4+S5+S6+S7+S8+S9+S10;
        28*a1+13.95*a2+7.254 *a3+s1<= 1616.985;
        (1*a1+1*a2+1*a3)*0.2+s2<=803.14;
        (1*a1+1*a2+1*a3)*0.75+s3<=535.425;
        (1*a1+1*a2+1*a3)*0.05+s4<=278.42;
        (1*a1+1*a2+1*a3)*0.5+s5<=803.14;
        (1*a1+1*a2+1*a3)*0.33+s6<=535.425;
        (1*a1+1*a2+1*a3)*0.2+s7<=278.42;
        (1*a1+1*a2+1*a3)*0.2+s8<=803.14;
        (1*a1+1*a2+1*a3)*0.75+s9<=535.425;
        (1*a1+1*a2+1*a3)*0.05+ s10<=278.42; end
```

Parking angle of 45°

```
Global optimal solution found.
Objective value:                              6467.940
Infeasibilities:                              0.000000
Total solver iterations:                             0
Elapsed runtime seconds:                          0.08

Model Class:                                        LP

Total variables:                    13
Nonlinear variables:                 0
Integer variables:                   0

Total constraints:                  11
Nonlinear constraints:               0

Total nonzero:                      53
Nonlinear nonzero:                   0

                         Variable           Value        Reduced Cost
                               A1        0.000000            30.03000
                               A2        0.000000            15.98000
                               A3        0.000000            9.284000
                               S1        1616.985            0.000000
                               S2        803.1400            0.000000
                               S3        535.4250            0.000000
                               S4        278.4200            0.000000
                               S5        803.1400            0.000000
                               S6        535.4250            0.000000
                               S7        278.4200            0.000000
                               S8        803.1400            0.000000
```

S9	535.4250	0.000000
S10	278.4200	0.00000

Row	Slack or Surplus	Dual Price
1	6467.940	1.000000
2	0.000000	1.000000
3	0.000000	1.000000
4	0.000000	1.000000
5	0.000000	1.000000
6	0.000000	1.000000
7	0.000000	1.000000
8	0.000000	1.000000
9	0.000000	1.000000
10	0.000000	1.000000
11	0.000000	1.000000

Parking angle with 60°

Global optimal solution found.		
Objective value:		5301.920
Infeasibilities:		0.000000
Total solver iterations:		0
Elapsed runtime seconds:		0.09
Model Class:		LP
Total variables:	13	
Nonlinear variables:	0	
Integer variables:	0	
Total constraints:	11	
Nonlinear constraints:	0	
Total nonzero:	53	
Nonlinear nonzero:	0	

Variable	Value	Reduced Cost
A1	0.000000	30.15500
A2	0.000000	14.53000
A3	0.000000	4.500000
S1	1325.480	0.000000
S2	658.3500	0.000000
S3	438.9000	0.000000
S4	228.2300	0.000000
S5	658.3500	0.000000
S6	438.9000	0.000000
S7	228.2300	0.000000
S8	658.3500	0.000000
S9	438.9000	0.000000
S10	228.2300	0.000000

Row	Slack or Surplus	Dual Price
1	5301.920	1.000000
2	0.000000	1.000000
3	0.000000	1.000000
4	0.000000	1.000000
5	0.000000	1.000000

6	0.000000	1.000000
7	0.000000	1.000000
8	0.000000	1.000000
9	0.000000	1.000000
10	0.000000	1.000000
11	0.000000	1.000000

Parking angle with 90°

Global optimal solution found.	
Objective value:	4530.000
Infeasibilities:	0.000000
Total solver iterations:	0
Elapsed runtime seconds:	0.09
Model Class:	LP
Total variables:	13
Nonlinear variables:	0
Integer variables:	0
Total constraints:	11
Nonlinear constraints:	0
Total nonzero:	53
Nonlinear nonzero:	0

Variable	Value	Reduced Cost
A1	0.000000	30.15500
A2	0.000000	15.98000
A3	0.000000	9.284000
S1	1132.500	0.000000
S2	562.5000	0.000000
S3	375.0000	0.000000
S4	195.0000	0.000000
S5	562.5000	0.000000
S6	375.0000	0.000000
S7	195.0000	0.000000
S8	562.5000	0.000000
S9	375.0000	0.000000
S10	195.0000	0.000000

Row	Slack or Surplus	Dual Price
1	4530.000	1.000000
2	0.000000	1.000000
3	0.000000	1.000000
4	0.000000	1.000000
5	0.000000	1.000000
6	0.000000	1.000000
7	0.000000	1.000000
8	0.000000	1.000000

Appendix-C

Survey Data from On-Street Parking Lot

		morning		Monday		afternoon			hourly total	arrival	arrival	arrival
	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60	vehicles	truck	cars	motorcycle
2hr-3hr	5	3	4	5	7	8	2	6	40	8	30	2
3hr-4hr	6	3	3	2	4	2	7	3	30	4	26	0
4hr-5hr	4	4	4	6	3	3	5	3	32	2	30	0
5hr-6hr	2	5	6	3	6	5	3	4	34	4	26	4
6hr-7hr	11	9	7	8	8	6	9	6	64	8	52	0
7hr-8hr	7	6	8	3	6	8	5	8	51	6	40	5
8hr-9hr	3	7	6	4	4	3	3	7	37	7	30	0
9hr-10hr	0	8	4	6	6	2	6	4	36	3	31	2
10hr-11hr	2	3	8	7	3	1	7	2	33	3	27	3
11hr-12hr	4	3	3	8	0	7	4	3	32	2	28	2
Daily total	44	51	53	52	47	45	51	46	389			
		morning		Tuesday		afternoon			Hourly total			
	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60	vehicles			
2hr-3hr	4	6	7	5	5	4	5	5	41	7	32	2
3hr-4hr	6	3	6	3	4	2	7	3	34	4	30	0
4hr-5hr	4	4	4	6	3	3	5	5	34	8	24	2
5hr-6hr	2	5	6	3	6	5	3	4	34	2	30	2
6hr-7hr	12	11	9	8	8	13	9	10	80	18	62	0
7hr-8hr	7	6	5	3	6	8	5	8	48	8	30	0
8hr-9hr	3	7	6	4	4	3	3	7	37	6	30	1
9hr-10hr	1	8	4	6	6	2	6	4	37	8	26	3
10hr-11hr	2	3	3	7	4	1	7	2	29	6	23	0
11hr-12hr	4	3	3	4	3	5	4	3	29	3	20	6
Daily total demand	45	56	53	49	49	46	54	51	403			
		morning		Wednesday		afternoon			Hourly total			

	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60	vehicles			
2hr-3hr	6	4	7	5	7	6	4	6	45	5	40	0
3hr-4hr	6	3	5	4	4	2	7	2	33	1	30	2
4hr-5hr	4	4	4	6	3	3	5	3	32	4	26	2
5hr-6hr	2	5	6	3	6	5	3	4	34	0	28	2
6hr-7hr	10	12	12	9	8	8	10	8	77	6	67	4
7hr-8hr	7	6	8	3	5	8	5	6	48	8	38	2
8hr-9hr	3	7	6	4	4	3	3	7	37	8	30	0
9hr-10hr	4	8	3	6	6	2	6	4	39	8	30	0
10hr-11hr	2	3	8	7	3	1	7	2	33	4	26	3
11hr-12hr	4	3	3	8	3	7	4	3	35	3	30	2
Daily total	48	55	62	55	49	45	54	45	413			
		morning		Thursday		afternoon			Hourly total	8	30	2
	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60	vehicles	8	30	2
2hr-3hr	7	6	4	5	4	6	4	6	42	8	32	2
3hr-4hr	6	3	4	2	4	2	7	4	32	3	28	1
4hr-5hr	4	4	4	6	6	3	5	3	35	8	25	2
5hr-6hr	2	5	6	3	6	5	3	4	34	2	32	0
6hr-7hr	10	12	12	9	9	8	10	8	78	10	68	0
7hr-8hr	7	6	8	3	6	8	5	8	51	8	41	2
8hr-9hr	3	7	6	4	4	3	3	7	37	7	30	0
9hr-10hr	4	8	4	6	6	2	6	4	40	4	34	2
10hr-11hr	2	3	8	7	3	1	7	2	33	0	33	0
11hr-12hr	4	2	4	8	3	6	4	3	34	6	29	0
Daily total	49	56	60	53	51	44	54	49	416			
		morning		Friday		afternoon			Hourly total	8	30	2
	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60	vehicles	8	30	2
2hr-3hr	5	8	6	4	7	7	6	6	49	10	39	0
3hr-4hr	4	3	3	2	4	2	7	3	28	4	24	0
4hr-5hr	4	4	4	6	3	3	5	3	32	0	32	0
5hr-6hr	2	5	6	3	6	5	3	4	34	0	34	0
6hr-7hr	10	12	12	9	9	8	10	8	78	10	68	0
7hr-8hr	5	8	8	3	4	8	5	8	49	5	31	6
8hr-9hr	3	7	6	4	4	3	3	7	37	6	27	4
9hr-10hr	4	8	4	6	6	2	6	4	40	0	40	0

10hr-11hr	3	3	8	7	2	2	7	2	34	8	24	2
11hr-12hr	4	3	3	8	3	7	4	3	35	9	25	0
Daily total	44	61	60	52	48	47	56	48	416			
		morning		Saturday		afternoon			Hourly total	8	30	2
	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60	vehicles	8	30	2
2hr-3hr	8	8	7	6	5	6	5	6	51	8	30	2
3hr-4hr	6	4	3	2	6	2	6	6	35	8	30	2
4hr-5hr	4	5	4	6	3	3	5	3	33	8	30	2
5hr-6hr	3	5	6	3	6	5	3	4	35	8	30	2
6hr-7hr	11	13	12	10	11	14	11	8	90	8	80	2
7hr-8hr	7	6	8	3	6	8	5	8	51	8	30	2
8hr-9hr	3	7	6	6	4	3	3	7	39	8	30	2
9hr-10hr	4	8	4	6	6	2	6	4	40	8	30	2
10hr-11hr	5	3	8	7	3	1	7	2	36	8	30	2
11hr-12hr	4	3	5	8	3	6	4	6	39	8	30	2
Daily total	55	62	63	57	53	50	55	54	449	8	30	2
		morning		Sunday		afternoon			Hourly total	8	30	2
	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60	vehicles	8	30	
2hr-3hr	3	4	0	1	3	0	0	2	13	0	11	2
3hr-4hr	3	3	3	2	4	2	4	1	22	5	13	4
4hr-5hr	4	4	4	6	3	3	5	3	32	2	29	1
5hr-6hr	2	5	2	3	3	5	3	4	27	7	18	2
6hr-7hr	6	7	6	5	4	6	6	6	46	8	36	2
7hr-8hr	3	6	4	3	3	0	5	4	28	2	24	2
8hr-9hr	3	4	3	4	4	3	3	7	31	2	21	8
9hr-10hr	0	3	4	4	0	2	6	4	23	0	18	5
10hr-11hr	2	3	4	2	3	1	4	2	21	6	15	0
11hr-12hr	4	2	3	0	3	3	2	3	20	0	22	0
Daily total	30	41	33	30	30	25	38	36	263			