



ADDIS ABABA UNIVERSITY INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

CIVIL AND ENVIRONMENTAL ENGINEERING DEPARTMENT

“Integration of Light Rail Transit with other Public Transport

Modes:

The case of East-West light Rail Transit Corridor in Addis Ababa”

By Bizunesh Aimero

Thesis submitted to

The school of graduate studies of Addis Ababa University in partial fulfillment of the

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Declaration

I, the undersigned, declare that this thesis is my original work, has not been presented for a degree in this or any other university, and all sources of materials used for the thesis have been fully acknowledged.

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This thesis has been submitted for examination with my approval as a university advisor.

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Abstract

This thesis was conducted to assess and review current public transportation system in Addis Ababa city and to highlight the challenges of transport system in Addis Ababa. It was also conducted to recommend efficient public transport system for the society by integrating demand responsive transport service with newly constructed light rail transport in the city along the selected corridor from Ayat to Meskel square.

The research was based on the primary data collected at the field and secondary data obtained from concerned government organization. Primary data were collected by identifying ten major stations and count the number of passenger originated from each station and travel time of the vehicles for each trip. The location of the stations also determine by using geographic positioning system (GPS).

This research tried to create an integrated network system between demand responsive vehicle (Minibus) and fixed route system (LRT) by using the software called TransCAD. The number of demand responsive vehicle needed for each trip was determined using excel software. Geographic information system (GIS) Arc map were also used to prepare and edit input data.

The results obtained through the assessment indicated the demand of the public transport and the provided services are not proportional in the city. It was found that shortage of service quantity, low level of safety, poor service quality, poor service accessibility, inappropriate vehicle type and size and lack of integrated network design are the major problems that exist in the city.

The overall finding of the thesis shows that 75.68% of the total trips use the existing route to travel from their origin to destination; around 10.81% of the trips use only light rail vehicles to travel from their origin to destination and the rest 13.51% of the trips use integrated trip.

In conclusion, this thesis highlighted the public transport system in the Addis Ababa and has identified the current problem that exists in the city and has established a physical integrated network along the selected light rail corridor.

Table of Contents

Acknowledgment	i
Abstract.....	ii
List of Tables	vii
List of Figures	viii
List of Acronyms.....	ix
1. INTRODUCTION.....	1
1.1 Background	1
1.2 Research problem	2
1.3 Research question.....	3
1.4 Objective	3
1.5 Scope and relevance of the study.....	4
1.6 Organization of the paper	5
2. LITERATURE REVIEW	6
2.1 Introduction	6
2.2 Urban Transport.....	7
2.2.1 Urban Transport Modes.....	7
2.2.2 Public Transport Mode.....	8
2.2.3 General Natures of Modern public transport	12
2.3 The Concept of ‘Integration’ in Public Transport.....	13
2.4 The Objectives of Integration in Public Transport	14
2.4.1 Physical integration.....	15
2.4.2 Network integration.....	15
2.4.3 Fare integration.....	17
2.4.4 Information integration	18
2.4.5 Institutional integration	18
2.5 Choosing Between Direct and Feeder Lines	19
2.6 Planning of Fixed Route Services	21
2.7 Demand Responsive Services.....	22
2.8 Planning of Integrated Services	24
2.9 Modeling of Integrated Services	28
2.10 A Method for Scheduling Integrated Transit Service.....	31

2.11. Determining the required number of vehicles	37
3.METHODOLOGY	39
3.1 Study Area	39
3.2 Data collection methods	39
3.3 Study strategy	40
3.4Method of data processing and analysis	42
3.4.1 Description of Trans CAD	42
3.4.2 Transit Networks and Paths	43
3.4.3 Input to TransCAD	43
3.4.4Output from TransCAD	43
4. ASSESSMENT OF CURRENT PUBLIC TRANSPORT SERVICE IN ADDIS ABABA.....	44
4.1 Introduction	44
4.2 Road Network in Addis Ababa	45
4.3 Structure and Organization of Urban Public Transport	46
4.4 Operational Characteristics.....	49
4.4.1 Routes operated	49
4.4.2 Scheduled Timetables	51
4.4.3 Vehicle Kilometers Run	52
4.4.4 Terminal management system	52
4.5 Identified Problems.....	53
4.5.1 Shortage of Service Providers	53
4.5. 2 Low Levels of Safety	53
4.5.3 Poor Service Quality.....	54
4 .5.4 Poor service accessibility.....	54
4.5.5 Inappropriate vehicle type and size	55
4.5. 6 Lack of Integrated Network Design.....	55
5. CASE STUDY: Addis Ababa from Ayat II to Meskel Square	56
5.1 General.....	56
5.2 Background	56
5.3 Route Descriptions	58
5.4 Converging Points	59
5.5 Operating characteristics	59

5.6 selected stations	61
5.7 Demand.....	62
6. ANALYSIS AND DISCUSSION	64
6.1 General.....	64
6.2 Inputs	64
6.3 Example of route development	68
6.4 Full analysis and discussion.....	70
6.4.1 Physical network integration	70
6.4.2 Number of demand responsive vehicle in each route.....	76
7. CONCLUSIONS AND RECOMMENDATIONS.....	79
7.1 Conclusions	79
7.2 Recommendations	80
7.3 Future Research Area.....	81
Appendix 1	82
8. REFERENCE.....	88

List of Tables

Table 1: public transport modes with corresponding advantage and disadvantage	12
Table 2: Constructed vehicular road coverage.....	46
Table 3 : Hourly distribution of demand.....	62
Table 5: "base condition" Euclidian and network distance	72
Table 6: Trip served by fixed route only	73
Table 7: Base condition of trips from origin to destination.....	74
Table 8: Trip served by integrated system.....	74
Table 9: Number of demand responsive vehicle (taxi) in each route.....	76

List of Figures

Figure 1: A horse car.....	9
Figure 2: A San Francisco cable car. San Francisco was the first city with cable cars.....	10
Figure 3: An early streetcar.....	10
Figure 4: A double-decker bus.....	11
Figure 5: Benefits of integrated service.....	25
Figure 6 : Description of integrated service.....	26
Figure 7: Different way of traveling with the integrated service.....	27
Figure 8: An integrated transit trip.....	33
Figure 9: Passenger route development.....	36
Figure 10: Research methodology chart.....	41
Figure 11: Buses and Minibuses in the city.....	49
Figure 12: Addis Ababa Light Rail Transit system network along both corridors.....	51
Figure 13: Long queue of passenger around bole.....	53
Figure 14: LRT Addis proposed routes.....	58
Figure 15: East West direction stations.....	59
Figure 16 : Physical connection locations between LRT and demand responsive routes.....	59
Figure 17 : Hourly distribution of the demand.....	63
Figure 18: Edited network map in ArcMap.....	66
Figure 19 : Passenger itinerary development.....	67
Figure 20: Way of traveling with the integrated service from "Kasanchis to Megenagna".....	68
Figure 21: Trans CAD result of total network layout of trip which use the existing network.....	75
Figure 22: Trans CAD result of total network layout of trip which use the integrated trip.....	75

List of Acronyms

AACRA- Addis Ababa City Road Authority

AATB- Addis Ababa Transport Bureau

ACBTE- Anbessa City Bus Transport Enterprise

ERTA- Ethiopian Road Transport Authority

GPS- Global Positioning System

GIS- Geographic Information System

LRT- Light Rail Transit

PTC- Passenger Transport Corporation

1. INTRODUCTION

1.1 Background

Transport is the engine of social and economic activities. The provision of competent and efficient transportation system is paramount importance for cities especially in the modern era of globalization and information age where cities are the centers of urbanization and propellers of national and global economies.

Mass transport provides an important mobility for people within urban area throughout the world. Increased demand for personal mobility aggravates the problems caused by traffic like congestion and environmental impact. Public transportation gets more and more important role in reducing these problems. Increased demand for public transportation opens up for lower headways and a more effective use of the vehicles.

Public transportation systems are evolving towards more flexible solutions, in order to better serve the needs of the population, to capture additional travel demands from other transportation modes. One such flexible solution is a demand responsive service integrated with fixed route.

This type of system can use the already existing fixed route service for the major part of the journeys and thereby only needs to use demand responsive service for shorter distances. Providing and improving urban public transport service is becoming highly important to meet the demand of rapidly growing mass mobility due to high population growth and urbanization in and around the city of Addis Ababa.

Addis Ababa, the capital city of Ethiopia, is the heart of social, political and economic activities of the country and is the 4th largest diplomatic center in the world as the city is a seat of UN Economic Commission for Africa (UNECA) and African Union (AU). Addis Ababa is experiencing a fast paced urbanization which imposes intense pressure on the urban infrastructures, particularly on transport.

Addis Ababa is already in peak pressure of providing competent transportation infrastructures and services that can absorb the pressing demand of the ever growing population. In light of this, the city is striving to alleviate the current transport problems and the inevitable future challenges through the introduction of LRT.

There were some researches done previously to improve the performance of public bus transport service of the city; however, there is no much works were done in integration of either public transports infrastructure or service. Since light rail transit is new to the city, it needs careful planning and integration with existing public transports infrastructure and service. This paper tries to integrate two modes of public transport providers namely minibuses and light rails to give seamless transport services along the East-West corridor between Ayat and Torhailoch within the city of Addis Ababa.

1.2 Research problem

Addis Ababa is the capital and the largest city of Ethiopia and it is the country's commercial, manufacturing, and cultural center. Public transport in Addis Ababa is provided by high-capacity buses operated by Anbessa, with a nominal capacity of 100 passengers, minibus with a capacity of 12 passengers and some other types of buses, which are owned by private operators. The population in the city has been increasing dramatically in the past few decades but the provision of transport facilities is not proportional to growth of the population. In order to avoid this problem and to fill the gap between the demand and the current transport supply, the Addis Ababa City Road Authority launched a large scale road projects and the Ethiopian Railway Corporation similarly launched a light rail transport facility.

The newly constructed LRT has two main corridors; one from Kality to Menelik Square (South-North) and the other from Ayat to Torhailoch (East-West). This LRT is proposed to serve a large number of public transport users and is expected to attract more users. This light rail transport by itself cannot avoid the current transport problem unless it is integrated

with other public transport providers like buses and taxis. Therefore, there should be a well organized and integrated public transportation system in the city.

1.3 Research question

The following seems possible research questions:

- What types of transport system are practiced in the city and how are these services compatible with one another?
- What are the real challenges of transport problems in Addis Ababa City?
- What should be the combination of demand responsive service with the fixed route service in order to give efficient service? What road network should demand responsive use on the current road network?
- What should be the optimal number of demand responsive vehicles in each identified route to integrate with the recently established light rail transit (LRT)?

1.4 Objective

- The general objective of this thesis is to create reliable and efficient public transport system for the city of Addis Ababa by integrating demand responsive road transport service with newly constructed light rail transit along the selected corridor. The research first tries to review the current transport system of the city. In addition, it tries to determine the network which will be demand responsive and the number of vehicles required to complement the LRT services.
- The specific objectives are to:-
 - assess the current public transport performance and highlight the challenges of transport system in Addis Ababa.
 - determine the number of trip originated and the number of passengers arrived at the major taxi stations within the study area.

-
- determine the combination of fixed route and demand responsive services by considering demand responsive vehicle as a feeder system to the light rail transit system.
 - determine the network for minibuses to have integrated system with LRT and their limit of service on the corridor.

1.5 Scope and relevance of the study

The scope of this thesis is limited to determining the integration (network) of taxis and LRT in east west direction from Ayat to Meskel square. The research assesses the current transport system in the city, collect relevant data, analyze the acquired data using Transcad, discussion on outputs and finally closing the research by putting conclusions and forwarding recommendations.

The paper will be relevant for public transport system by introducing integrated transport system among different mode of transport. It will be also helpful for planning of integrated service in different organization like Addis Ababa Transport Authority (AATA) and Addis Ababa City Road Authority (AACRA). It will provide as an initial idea for further research for other professionals and practitioners in respective disciplines.

1.6 Organization of the paper

The paper is organized in six chapters and the description of each chapter is as follow

Chapter one – It is general introduction about the paper and it include Background, research problem, research question, objective, methodology and scope and relevance of the study.

Chapter two- Describe and assess different papers and previously done works related with integrated public transport system.

Chapter three- Overview of transport system in Addis Ababa will be discussed in this chapter. Structure and organization of urban public transport and operational characteristic of the system are also included.

Chapter four- case study and it describe the background of the area, network description and operational characteristics of the selected area.

Chapter five- Discusses research findings and analyses of the case studies on the basis of identified results.

Chapter six- Conclusion based on the result and recommendation.

2. LITERATURE REVIEW

2.1 Introduction

An increased demand for personal mobility also increases the problems caused by traffic. Public transportation gets a more and more important role in reducing these problems. Increased demand for public transportation opens up for lower head ways and a more effective use of the vehicles. Because of this, the level of service can improve with an increased demand, which is hardly the case for private transportation. This emphasizes that when the demand of personal transport increases, so do the importance of a well functioning public transport system. However, by considering the daily increment in environmental emission, specifically air pollution produced by vehicles, and the limitation of natural resources, it is obvious that increasing car-based trips is a critical threat to the global environment. In addition, congestion is a big issue in urban areas which negatively affects the people's lives in different aspects [1]. With this in mind, the improvement of public transport systems, as a sustainable alternative to car-based trips, is becoming more and more crucial amongst decision makers. Consequently, the extension of different public transport modes, such as rail and bus, are given special attention and considerable budgets are invested on this purpose.

Public transportation systems are evolving towards more flexible solutions, in order to better serve the needs of the population, to capture additional travel demands from other transportation modes and of course to increase profitability. One such flexible solution is a demand responsive service integrated with a fixed route. This type of system can use the already existing fixed route service for the major part of the journeys and thereby only needs to use the more expensive demand responsive service for shorter distances. Integrated services can be used to extend the public transportation service into low-density markets (both low-density areas, as well as to new customer segments) or can be used to substitute parts of the fixed route service [2].

2.2 Urban Transport

It is commonly accepted that cities are the engines of growth in most developing as well as developed countries. More importantly, urban transport can be viewed as the oil that prevents this engine from seizing up.

Transportation is also diverse. It is multi-sector and, as such, it needs to be fully integrated with other municipal sectors. New transport infrastructure must be part of a balanced urban development program including traffic demand management, public transport provision and supporting land use policies [3].

Economically, transport is an essential element of city development that, in turn, is a major source of national economic growth. *Simply stated, poor transport inhibits growth.* Furthermore, socially, transport is the means of accessibility to jobs, health education and social services essential to the welfare of the city residents. *Deteriorating transport conditions affect all city residents; they impact particularly the poor through a decline in public transport service levels, increased length of the journey to work and other essential services and the negative impacts on environment, safety and security that the poor are least able to mitigate.*

The urban sector in most developing countries accounts for at least 50 % of the gross national product and in some countries over 70 %. Cities in developing countries often devote 15% to 25% of their annual expenditures to their transport system and sometimes much more [3].

2.2. 1 Urban Transport Modes

Urban transport is broadly categorized into motorized or non-motorized modes. The choice of a particular mode of urban transport depends on such factors as accessibility and ease of operation. Non-motorized modes include Animal drawn Mode, Walking mode, and Bicycle. Whereas motorized modes includes Railways, Air plane, and Vehicular and Motor cycle

2.2.2 Public Transport Mode

The History of Public Transport

The first public transportation known to history was introduced by the Romans, that established a system of vehicles for hire during the reigns of Emperors Augustus and Tiberius [4]. These two- or four-wheel wagons were stationed at inns every five or six miles along the fine highways for which the Romans were famous.

Coaches that ran on regular schedules between major towns appeared in Europe during the 16th century. Stagecoaches were introduced in the 17th century. However, most roads were poor, fares were high, and the service was slow and uncomfortable.

The first form of public transportation to operate solely within cities was the “*hackney carriage*”, the forerunner of the taxi, which appeared in Paris and London shortly after 1600. The name came from the French word “*haquenee*”, meaning a horse of fair size and quality used for riding, but not for war or hunting.

In 1662 the French philosopher-mathematician Blaise Pascal obtained a patent from the King and began a low-fare coach service on five fixed routes in Paris. Although successful at first, the service lasted less than 2 years. This was partly because Pascal died, at the age of 39, but also because hackneys offered competition and people in certain classes (e.g., soldiers and servants) were not allowed to ride the coaches [4]

As the 19th century opened, the average person walked to work. Cities were dense and compact; the geographical area of a city was largely limited to the radius of walking distance from the center. Some wealthy families lived on the outskirts and traveled by horseback or carriage, but horses were too expensive for common people to keep.

The modern era of urban mass transit began in 1819 with a coach line in Paris [5]. It used an existing type of stagecoach called “*a diligence*”. The first transit service in the United States was started by Abraham Brower on Broadway in New York City in

1827. For this he designed a modified stagecoach seating 12 passengers, it was named “*the Accommodation*”. The second generation of this stagecoach had a different design: all the seats ran lengthwise, and there was a door at the rear with an iron stairway to the ground. This vehicle was named the “*Sociable*”.

Development of Public Transport

➤ Omnibus

In 1825, a coach builder named George Shillibeer built specially designed coaches with large seating capacity for use in Paris. The vehicle was called *an omnibus*.

➤ Horse-Drawn Street Railway

A major advance came in the form of the horse-drawn street railway. The first one in the world was the New York & Harlem Railroad, which began service in 1832. The use of horses was first considered temporary, but the horses performed well and were never replaced by steam engines.



Figure 1: A horse car

➤ Cable Car

In this system, a cable is laid in a small trough between the rails and is kept in continuous motion by a steam engine located at the end of the line. A car is propelled by gripping onto the cable with a metal arm that reaches down; the grip is released when the car brakes to a

stop. The car itself has no motor. Besides a driver-conductor, each car carries a grip man, who must develop skills at the trade.



Figure 2: A San Francisco cable car. San Francisco was the first city with cable cars

➤ **Electric Streetcar**

The streetcar-also called the electric railway, trolley, or tram-was the next and most important innovation.



Figure 3: An early streetcar

➤ **The Steam Railroads**

The 19th century also witnessed the development of steam railroads. The first intercity railroad service began in 1830 between Liverpool and Manchester in England. This inaugurated a century in which steel wheels on steel rails became the dominant form of intercity transportation. The railroad industry formed a major part of the economy, much as the automotive industry does now.

➤ **Subway and Elevated Systems**

Several attempts were made to introduce steam trains into the heart of cities. The first Subway in the world, 3.7 miles long, opened in London on January 10, 1863 [6]. The trains were pulled by steam locomotives, and while special efforts were made to expel the smoke, ventilation remained a major problem. The line was popularly called “the sewer railway”. However, it continued to operate for many years and eventually was electrified.

➤ **Arrival of the Motor Vehicle**

The forerunner of the private motor vehicle was the road locomotive or steam carriage. This was a steam engine on wheels-something like a railroad locomotive, but with flat surfaced wheels to run on highways.



Figure 4: A double-decker bus

2.2.3 General Natures of Modern public transport

Various studies have classified Modern public transport in to four general categories based on their nature of operation. These are:

1. Buses and trolley buses: - operate on public streets in either mixed traffic or bus only lanes or exclusive bus ways. They employ engines that use fuel and or electric energy. Electric buses usually run with the help of cables that are mounted on electric poles which run along the whole line.
2. Light rail transit Trains: - operate in mixed traffic along public streets to semimetro rail systems on exclusive trucks.
3. Rapid rail transit (Metro, subways or underground): - operates on exclusively right-of-ways at high speed and high capacity passengers' board from high-level platform to facilitate rapid loading.
4. Sub-urban rail transit (Commuter rail system): - operates on trucks shared with inter-city passenger crews and freight.

Urban Mass Transport systems can also be classified based on the line system they employ.

- On-street systems: buses; trolley-buses; trams.
- Mixed on-street and off-street systems: bus lanes; bus ways; light rail.
- Off - street systems: metros; commuter-rail.

Comparison of Public Transport Modes

Table 1: public transport modes with corresponding advantage and disadvantage

Public transport mode	Advantage	disadvantage
City - Bus Service	<ul style="list-style-type: none">• Can be used on the existing streets• Low cost of investment (initial)• Flexibility in use on steeps streets.• Accustomed technology (easy to maintain, operate, etc.)	<ul style="list-style-type: none">• Pollution and excessive noise• Long waiting time where there is no only bus lane

	<ul style="list-style-type: none"> • Affordability • Environmentally friendly, in the case of electric bus. 	<ul style="list-style-type: none"> • Moves fewer travelers (in comparison to light rail transit)
Light Rail Transit	<ul style="list-style-type: none"> • In most case, the existing rail line can be utilized. • Consumes less energy than buses • Can move more people • Emits less pollution • Reduces congestion on the street 	<ul style="list-style-type: none"> • Inflexibility (existence of line and slope to be crossed) • Expensive truck maintenance • High initial cost (construction of line, demolitions) • Users should change mode of transport beyond the end of the line.
Trolley-Bus	<ul style="list-style-type: none"> • Environmentally friendly • Can move more people • Cheaper operation cost than normal buses • Reduces traffic congestion on streets. 	<ul style="list-style-type: none"> • Very high initial cost • Relatively high electric consumption • Doesn't provide flexibility

2.3 The Concept of ‘Integration’ in Public Transport

The term of ‘*integration*’ in public transport or ‘*integrated public transport*’ is similar to the concept of intermodal which is generally used for the transport of goods. This concept is generally defined as a system that provides seamless (or ideally door-to-door) public transport services for passengers. However, there has not been a standard definition of this term yet [7]. In fact, the concept of integration in public transport is discussed and advocated in a variety of studies but rarely defined.

The word ‘integration’ used in public transport covers a wide range of concepts. For instance, some studies define it as ‘*the way parts of the public transport network are*

embedded in the total mobility chain'. However, [8] defines integration by further and more comprehensive statement as:

“ The organization process through which elements of the passenger transport system (network and infrastructure, tariffs and ticketing, information and marketing, etc.) are, across modes and operators, brought into closer and more efficient interaction, resulting in an overall positive enhancement to the overall state and quality of the services linked to the individual travel components.”

This definition emphasizes that integration is a process rather than a state and it is assumed to be less efficient and less close in the absence of an appropriate process. Furthermore, it refers to all characteristics of the passenger transport service, including infrastructures, tariff and information systems and especially the authorities and organizations which are involved in planning, managing and running the public transport systems. This definition even goes further than the borders of public transport systems and includes wider integration with other transport modes (e.g. walking, cycling and private cars) and other non-transport services such as town planning and environmental and social policies [8]. Moreover, this definition clarifies that integration refers to both inter-modal and intra-modal issues. That is, it covers not only the interaction between different public transport modes, but also within each mode, by itself. In one word, integration refers to the speedy, convenient and economical connection of services provided by public transport systems in order to make up complete journeys for passengers from their origins to the final destinations [9].

2.4 The Objectives of Integration in Public Transport

The objective of ‘integrated public transport’ is to provide a seamless service using two or more modes in order to achieve a high level of modal share by attracting more passengers, especially car users [9]. In other words, integration is aimed to increase the ridership of

public transport systems in competition with private cars. Hence, it should be noted that integration is not a target by itself and implementation of it is not an end. In contrast, integration is a package of policies and activities that can improve public transportation system connectivity and reliability and make it more attractive travel alternative to the cars [1].

Integration in public transport can be done through physical integration, network integration, fare integration, information integration and intuitional integration. In this thesis we only try to see the network integration in public transport.

2.4.1 Physical integration

As every trip begins and ends on foot, walking should be appropriately integrated as one of the transport modes to the public transport systems. In this term, interchanges between transport modes are where the most barriers exist. Therefore, the main aim in this case is to minimize the obstacles related to the transfers. Walkways should be carefully designed to facilitate the transfer of passengers from one mode to another [10]. Facilitating of transferring between modes by reducing the walking distances and providing well-designed ramps and stairs can guarantee ease and safety of transfers amongst modes.

A fundamental element of a seamless public transport journey is the need to reduce the costs associated with interchanges. These costs can affect the demand for public transport in terms of the influences that interchanges have on waiting time, transferring time between vehicles, the attendant risks and inconvenience. Some studies have highlighted that the desirability of interchanges is influenced by interchange attributes, including personal security and travel information [1].

2.4.2 Network integration

Generally, public transport services are more attractive when they are given over a comprehensive network. Network integration is often interpreted as the formation of a

structure where performs a specific role in the system, making use of its relative benefits. This concept is also referred to the coordination and the links between long-distance public transport networks and local public transport networks. Based on this principle, the various modes have to be utilized according to their relative advantages by accumulating streams of passengers to higher ranking modes, like railway systems. Moreover, it plays as important role at the service planning stage, which consists of route and timetable design, by ensuring that services provide attractive ‘connection’ to each other in both terms of time and transfer conditions. Therefore, this aspect is classified to the integration of route network and timetable (scheduling).

- *Route Network*

This term is normally referred to the connectivity of the route network of different public transport modes. Bus and rail systems should be integrated in their own right and also these two separate networks should further complement each other. Feeder services (e.g. buses, taxi and light rail systems) should be designed so that they maximize the ridership of trunk routes where mass transit modes operate on. Network integration is closely linked to physical integration and both of them contribute towards the integration of infrastructure [10]. This has significant effects on the planning of fixed infrastructure, including main interchanges. Network integration not only should be considered at the both stages of planning and operation, but also it should be satisfied in terms of the coordination in investing on the infrastructures and main interchanges between public transports modes. Also at the operational level, it is referred to predicted or unpredicted excess demand or service disruption are taken into account by providing guaranteed interchanges, helpful information and alternative services in cases of delays or service failures [8].

- *Scheduling*

Scheduling analysis is often highly mathematically oriented to operational or safety analysis rather than being related to the practical considerations of route networks. Guihare and Hao emphasize the mathematical optimization and maximization equations of algorithms rather than practical planning principles that are normally followed by planners

to achieve seamless ‘*network effect*’ in public transport operation. However, [8] suggest the methods which are more practical and easily-applied in comparison with these approaches. Instead of mathematical computer model, they suggest easily creating a simple sketch map of public transport routes to combine the information from the network map and the timetables to have an important basic tool for network planning. In other words, while scheduling tasks are certainly important in designing a fast efficient network, planners should look first to network design in order to overcome the network problems and weaknesses. Although scheduling of services on individual lines is important to maximize their capacity (e.g. high-frequency metro systems in contemporary cities), wider attention should be paid on the network connectivity especially in dispersed metropolitan areas with fewer high capacity trunk lines [8].

2.4.3 Fare integration

This aspect of integration is simply referred to use a single fare ticket or card for multiple services which facilitates the transfer between modes. The two distinct issues of tariff and ticket integration are often considered as almost the same to the concept of integration itself. In fact, ticketing integration and fare integration are meant to facilitate traveling from the view of passengers. In other words, it is to remove the obstacles of using different services, such as different prices between similar journeys provided by a single or multiple operators or the different ticket types between two or more transport modes [8].

Although transfer of tickets between services may lead to some loss of revenue, the ridership increment would compensate this if the public transport is made more attractive [9]. In addition, *Rebates* can also be considered as an incentive for those who transfer from one mode to another.

2.4.4 Information integration

A comprehensive, easy-to-use passenger travel guide is a critical element of a successful multi-modal travel. Stations and stops are decision making points over the public transport networks. Therefore, the signage should be appropriately designed at bus and rail stations to convey effective information to passengers.

In one word, information integration states that the system is recognized as ‘one’, with unified set of concepts and a common language in the communication towards the passengers. The integrated information is aimed to remove the barriers of utilization of the system and to inform the passengers about the possibilities of travel offered by the system as a whole, both within and outside the public transport system [8]. Information Technology (IT) and Intelligent Transport Systems (ITS) can play important roles in this aspect of integration by providing clear, brief and timely information. The information should be clear, brief and timely. Furthermore, giving special attention to the elderly and the disable is a key point in terms of information integration.

2.4.5 Institutional integration

Although the operational integration in public transport, like integration of fares, information and services and infrastructure, have always been crucial, a further form of integration is required to facilitate and guarantee implementation of other integration aspects. This form is directly relevant to strategy formulation. Institutional integration, which is sometimes entitled ‘wider integration’, considerably affects other aspects of integration mentioned in the previous parts. This is involved in two main issues. At the lower level, it means the integration of public transport systems in their own right; between different modes and operators; and also with other transport systems (e.g. private cars, taxis, cycling and walking), at the stages of investment, service planning and operation. At the higher level, it is referred to the integration with other policy frameworks which are

associated with transport policies, including urban planning, environmental policies and social systems (e.g. health, social services and educational systems) [1].

2.5 Choosing Between Direct and Feeder Lines

The main argument usually put forward in favour of the direct line approach, is that bus passengers have a strong resistance to transfers, due to the extra time and inconvenience of having to change modes in the middle of their journey. In many cases the introduction of a forced transfer will make the users switch to the car instead of travelling by public transport.

Often it is also claimed that the direct bus solution is cheaper and more flexible to operate than a combination of local feeder bus and a rail service to the regional centre.

The normal objections to the direct bus solutions are that parallel running of bus and rail into the regional centre is a waste of resources due to under-use of train and rail capacity, that too many buses create congestion and environmental problems in the city centre, and that the journey by direct bus is slower and less comfortable than the alternative train journey on the main leg into the centre [11].

The main argument in favour of the feeder solution are that this system creates a more integrated network with better local travel opportunities by the transfer of operating resources from parallel bus and rail operation to a more economic division of roles between bus and rail.

It is also pointed out that travel speed on rail is faster, more comfortable and more reliable than buses on the main roads into the city centre, and that the upgrading of the bus system in the corridors into the city centre is difficult and costly compared to the operation of trains on segregated rights-of-way. It is also claimed that feeder services are needed to make good use of the high capacity of the train system and support high frequency services in the main

corridors. A feeder service can often provide a more frequent and useful local service and thus generate more local journeys if there is potential in the market [11].

Similar arguments may be used in the discussion of feeder lines to trunk bus services as to rail services, but the argument tends to be more heated when the alternatives also imply that different operators are losing or gaining business opportunities in the market.

The importance of the network effect for overall public transport use has been stressed already.

But obviously the best answer to the choice between direct and feeder bus depends on a number of considerations and local circumstances. For short journeys, the forced need to transfer is a substantial disincentive to use public transport. For longer journeys, the best solution for the user depends on a number of factors [11].

- Are there any cost or time savings or changes in comfort by choosing either the transfer or direct line service?
- How punctual and reliable are the different alternatives?
- What are the service frequencies of the different alternatives, both at peak hours and in weak traffic periods?
- Does the system design, information and ticketing systems support “seamless” travel, or is the journey very complex and without through ticketing?
- What sort of place is the interchange? Is it a simple bus or train stop with no extra services, or is it a major service and employment centre?
- Are there other important travel destinations on the same local feeder lines?

Research into the perceived travel penalty for the users due to interchanges has given some interesting results, briefly mentioned already. Users with experience of high quality interchanges have much smaller resistance than those direct bus users that are asked of their likely reactions to hypothetical, forced transfers.

2.6 Planning of Fixed Route Services

To be able to start the planning process, demand data must be accessible. The problem of estimating OD-matrices for transit networks is described in [12]. The data to the OD-matrices are many times gathered through on-board measurements instead of through estimation. Demand data is used in both the network design as well as in the timetabling of the service. The estimation, or gathering, of demand data is therefore very important.

The network design affects frequency setting as well as vehicle and crew scheduling. Because of this, the design step is very important. The problem known as the "Transit Route Network Design Problem" often includes both the actual network design problem as well as the frequency setting.

In [13], the problem of setting frequencies are addressed through the use of two multi-commodity flow models, both with the objective to minimize a combination of operating costs and passenger traveling time.

How the timetables are planned, highly affects the customers. This is an area where a lot of work has been done. Many times the objective is to minimize the total waiting time or the sum of the waiting time and the ride time. In [14], the objective is to find departure times at the terminal stations of all routes (busses and trains) so that the total waiting times at transfer nodes for all passengers is minimized. The work contains heuristics, regret-methods with improvement algorithms and simulated annealing, as well as a branch and bound algorithm. [15] Describes software designed for the synchronization of transfers. The software uses a model that from a set of possible starting times for different routes chooses the best one, with the objective to minimize the total penalty associated with transfers.

In [16] the problem of creating a time table with maximum synchronization given a network of a fixed route bus service is addressed. This is done with the object to maximize the number of buses simultaneously arriving at the transfer nodes of the network. The

problem is formulated as a mixed integer linear programming problem and a heuristic is used to solve the problem in polynomial time. The problem of synchronization is also addressed in the work of [17] that used a quadratic assignment problem to model the minimization of passengers waiting times at transfer nodes.

In [18], an exact formulation as well as two heuristic approaches to the “multiple depot vehicle scheduling problem with route time constraints” is presented. This problem is to create schedules for individual vehicles, busses, belonging to different operators and stationed at different depots. To add the route time constraints is to say that a specific vehicle must return to the depot within a given time. This can for example be due to fuel consumption or working hours of the driver. Adding this constraint for each vehicle reduces the size of the problem significantly. In [16] both timetabling and vehicle scheduling are handled.

This section has shortly described what has been done on the different problems in the strategic planning of a fixed route service. As can be seen from this literature review, optimization can be used to address all the problems in the strategic planning process of a fixed route service.

2.7 Demand Responsive Services

Fixed route services are not always enough to satisfy the needs of all customers who want to use the public transport service. Demand responsive services are therefore often a necessity to satisfy all the demand. The term “demand responsive service” is a label used for many different services. According to the definition of [19] a demand responsive transit service is a service that “provides door-to-door service on demand to a number of travelers with different origins and destinations”.

The door-to-door part of this definition is usually not so strictly followed. Many services do not pick up and drop off passengers at exact addresses, but the service still respond to a certain demand at a specific time. A better description of the service is that it offers flexible

routes and schedules and that it at least partially responds to requests from passengers. Demand responsive services are meant to fill the gap between fixed route mass transit and ordinary taxi service, both in terms of flexibility as well as in terms of cost [2].

In this section, different forms of demand responsive services will be described. Some of the forms of demand responsive services are similar to a fixed route service, while others are more of area covering services. The main types are:

- **Hail-a-Ride** is a fixed route service in local areas. The routes are normally highly frequented and provide access to healthcare, schools, shopping centers etc. Passengers can be picked up or dropped off anywhere along the route, i.e. embarking and disembarking is allowed anywhere along the route. Since this is still a fixed route service, it is the least flexible form of demand responsive services.
- **Route deviation** is a form of demand responsive service with low flexibility. The service is normally used in low-density areas, which also implies a low frequency of the service. The passengers, who are not able to reach the ordinary bus stops, can call in a request in advance so that the bus driver becomes aware of that a passenger wishes to be picked-up on the deviation part of the route. Unless a request has been called in, the bus travels the ordinary way, without the deviation.
- **Dial-a-Ride** is a type of service in which passengers can (and in most cases should) call in requests in advance. Normally this service operates between two scheduled stops, and the most common is to let the vehicle travel freely within a corridor between the two stops, rather than along a fixed route. Often, dial-a-ride services are also operated as a multi hire taxi, but serving a predefined area.
- **Multi-hire taxi** operates as a normal taxi, but the vehicle can be shared with other passengers traveling between other origins and destinations. This is the most flexible form of demand responsive service.

2.8 Planning of Integrated Services

An integrated service built up by a demand responsive service and a fixed route service can be designed in a number of ways. The differences between these designs primarily depend on what type of demand responsive service that is used. If elderly and disabled shall be able to use the integrated service, it is essential that the service can be provided very close to the desired points of origin and destination (or even at the exact addresses). The demand responsive service must therefore be an area covering service and there are two main services of interest. These two are dial-a-ride and multi hire taxi.

The demand responsive service can be used to carry passengers from their origin to an appropriate transfer location to the fixed route network, and/or from the fixed route network to their destination. It may be of great advantage to the provider of public transportation, due to cost effectiveness if a demand responsive service could be combined with the fixed route service. Also the passengers can benefit from this due to increased availability to the public transport service, and an increased level of service. These benefits of an integrated service are described in Figure , and are also the reason that many transit agencies have considered this possibility [2].

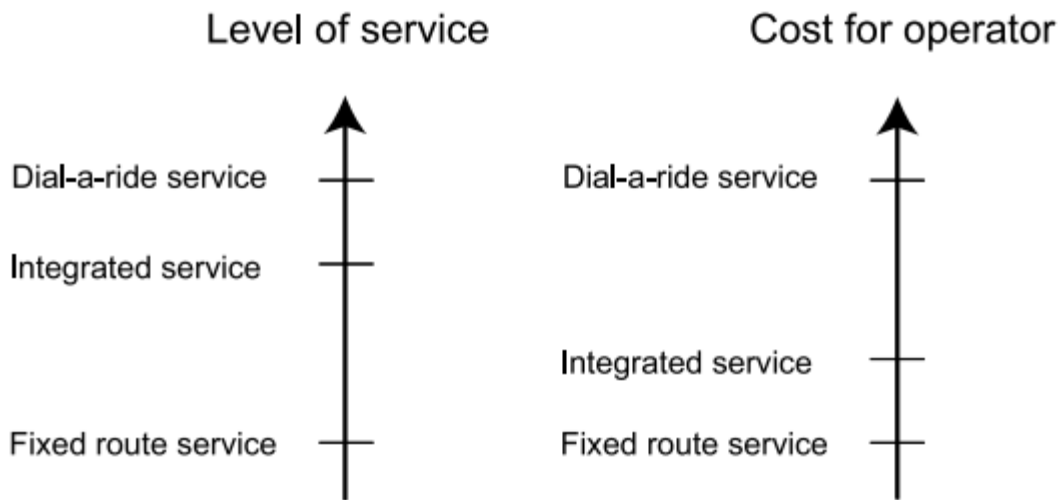


Figure 5: Benefits of integrated service

Most applications and modeling methods involving dial-a-ride systems are made from the operator's perspective. The objective is then to minimize the total travel distance, or a generalized cost, of the demand responsive vehicles subject to constraints regarding time-windows for requests and vehicle capacities. From the passengers perspective the total travel time is more relevant, but usually not included in the objective function. An ordinary taxi service operates from this perspective, since when no ride sharing occurs this is the most economical way to handle the requests.

This way to operate the vehicle fleet is a quite expensive one. In the case of taxi customers, these customers themselves have to pay for the high expense of this service. But in the case of integrated traffic the operator is more interested in minimizing the first objective, since this minimizes several variable costs such as the number of vehicles and drivers needed, fuel consumption etc.

The integrated service is intended to be used in such a way that a user can travel with the demand responsive service to a transfer point connecting the demand responsive service to the bus network. Transfer points are the bus stops at which it is possible to change between a demand responsive vehicle and a fixed route bus, and vice versa. If necessary, the

passenger can then transfer again from another transfer point in the bus network to a second demand responsive vehicle, operating in another area of the city, and with this vehicle travel to the destination. The journey can of course also include transfers between bus lines. A typical route, including two demand responsive vehicles, is described in Figure .

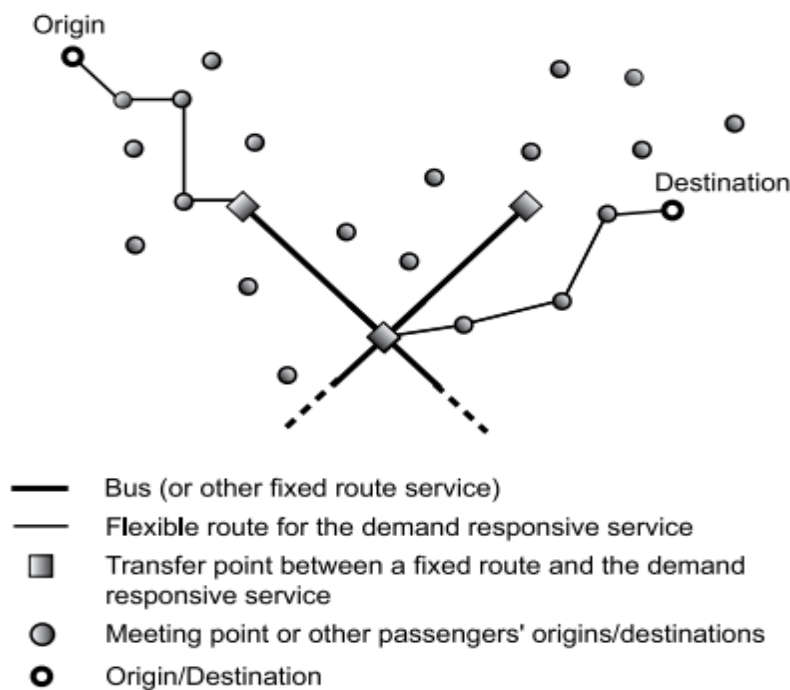


Figure 6: Description of integrated service

Alternative use of the integrated service include only one demand responsive vehicle in addition to the fixed route bus service for travel from an origin to a destination, or include one single demand responsive vehicle taking the passenger all the way from origin to destination. The relative use of these alternatives depends on the demand pattern, the cost structure and on the service levels offered to the customer. These factors also affect the overall performance of the integrated service.

The above description shows how the service is intended to be used when passengers are picked up and dropped off at the exact addresses of their origin and destination, i.e. when door to-door service is provided. Another way of operating the service is to use a large number of meeting points (bus stops for the demand responsive service) scattered over

the area where the service shall be available. The only difference is that the customers have to walk to, and from, these meeting points. By this reason it is very important that a large number of meeting points are used. In this way, journeys can be built up in the different ways presented in Figure .

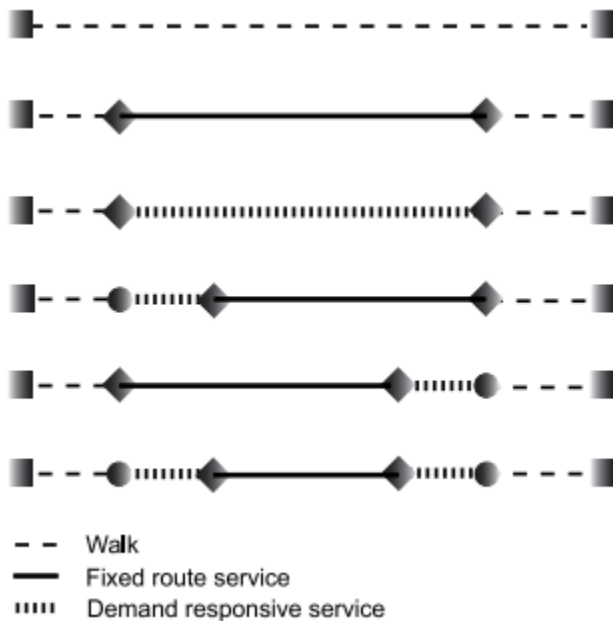


Figure 7: Different way of traveling with the integrated service

The fixed route service could be of any kind suitable for urban traffic, for example bus, tram or light rail. The fixed route service should have highly frequented routes. If routes with low departure frequencies should be used, coordination at the transfer locations must be made between the vehicles, and in this way complicating the construction of integrated journeys. The use of low frequented routes without any coordination to the demand responsive vehicles increases the transfer times [2]. In case of coordination between a demands responsive service and a fixed route service there are the additional problem of different travel times for the demand responsive service. This type of problem is very complex since the travel time depends on what requests that have been assigned to the

specific demand responsive vehicle. Timetable planning for integrated services is an area where more work must be made [2].

2.9 Modeling of Integrated Services

Integration between different services with fixed routes is not anything new. For example, busses arriving at train stations, even with coordinated timetables between the two transportation modes have been around for quite some time. The problem of scheduling an integrated service consisting of two fixed route services, train and bus, operated by two different operators are for example studied in Li & Lam (2004). [21] a combination of train and bus services is studied.

The problem is to design a feeder bus network given a rail network, with the objective to minimize a cost function considering both the operator's and the customers' interests.

The main difficulty of operating an integrated service is to schedule transit trips as a combination of demand responsive and fixed route transit service. Both passenger trips and vehicle trips must be scheduled, and it therefore makes the planning of an integrated service more complex than that of a single mode service. To solve the problem of scheduling trips to an integrated public transport service, a number of inputs are important to be known, and can be regarded as essential.

- the location of the passengers' origins and destinations
- the location of fixed route stops
- the schedules of all fixed route vehicles
- the time windows in which demand responsive vehicles are permitted to meet fixed route vehicles at transfer points
- vehicle capacities
- passenger loading and unloading time

-
- the distance between stops
 - minimum passenger level of service standards

The work of Wilson et al. (1976) is more focused on algorithms for planning the journeys. The problem has a passenger utility function as its objective, and this function is maximized subject to a series of level of service constraints. In this way, the costs of the operator are not included explicitly in the model. A trip insertion heuristic is used to schedule both passenger and vehicle trips. Opposite to this, the work of Liaw et al. (1996) has a model for the integrated problem with the operating costs as its objective.

Hickman & Blume (2001) take both passengers and operators objectives into account, by explicitly inserting the transit agency cost as well as the passenger level of service in the model. The goal in scheduling vehicle trips is from the operator's perspective to minimize the total cost of the service, while it from the passengers' perspective is to maximize the level of service; i.e., minimize travel time, transfer time and the number of transfers. The way this is implemented, so that the objectives of the operator and the passengers are balanced, is a heuristic that schedules the integrated trips in a way so the operators costs minimizes, subject to passenger level-of service constraints.

The method proposed divides the problem into two parts. The first part is to find feasible itineraries, for the requests suitable to integrated service, that connect the passenger's origin and destination in a way that maximizes the traveler's level of service. If the itinerary meets all of the level of service constraints, the trip is scheduled. The second part is that the demand responsive legs of the passenger's itinerary must be added to a specific vehicle, so that the legs are included in a vehicle's schedule. This is done in a way that minimizes the costs of the operator. The thoughts behind this decomposition was to make the technique improved over that of Liaw et al. (1996), by having the passenger's level of service considered explicitly, and over that of Wilson et al. (1976) by explicitly including operating costs into the decision making process of the vehicle scheduling.

In Horn (2002) the way a dial-a-ride system interacts with long-distance transportation systems have been studied. Procedures for planning journeys combining fixed route and demand responsive modes are further described in Horn (2004). The tests made with simulated demand shows that the procedures are well suited for a real time traveler information system.

In Aldaihani&Dessouky (2003), the objective function contains two measures of performance, minimize total travel distance of demand responsive vehicles and minimize total travel time of passengers. The proposed heuristic is tested on real-life data obtained from Antelope Valley Transit Authority. Regarding the methods proposed to solve this problem it is assumed that the requests are known before the scheduling process takes place, i.e. a static problem is considered. In the model it is further assumed that all demand responsive vehicles dispatches from, and at the end of the day must return to, their depot. The capacity of the fixed route buses is assumed enough not to be considered as a constraint, whereas the demand responsive vehicle have known capacity. The method is also based on the fact that a maximum of two transfers is allowed.

Another important problem regarding integration between a demand responsive service and a fixed route service is how to design the zones in which the service should operate, and to decide what geographical areas that have interest for such a service. The purpose of Durvasula et al. (1998) was to demonstrate the technical feasibility of operating a route deviation bus service, and in that way show that spatial analysis capacities provided by a GIS, can be used to support the operations of a route deviation service. To achieve this, design alternatives for a route deviation service where investigated. As a part of this work, the effects on the system depending on the service zone size where analyzed.

Analysis somewhat like these, but for an integrated service is presented in Aldaihani et al. (2004). An analytical model meant to be an aid in designing the network of an integrated service is developed. The problem has an area divided into zones, by a fixed route grid, where each zone is served by a number of demand responsive vehicles. If the destination

of a request is in another zone, then the demand responsive vehicles transfer the passenger to a fixed route. Since a grid structure of the fixed routes is assumed, it is possible to travel from any zone to all the others. If the destination of a request is in the same zone, the demand responsive vehicle will transport the passenger from the origin to the destination. The model developed in (Aldaihani et al. 2004) determines the number of zones, demand responsive vehicles, fixed routes, and buses in each route. This is done in the way that minimizes the total cost, as a combination of both the operator's and the passengers' costs. It should be noted that in this model only one passenger (or group of passengers with the same origin and destination) is served at a time by a demand responsive vehicle. That is, no ridesharing is allowed.

The work of (Carl, 2006) also concerns how a service should be designed. A demand responsive service is to be designed to feed a train station in a so effective way as possible. This study is done by simulation, and ten different routing strategies are simulated.

As can be seen by this literature review, most work in the field of integrated public transport systems have been made on heuristics to solve the problem of assigning passengers to vehicles. The complexity of this problem indicates that heuristics are necessary for operational planning in real time. For strategic planning the algorithms does not have to work in real time, and therefore exact models can in some situations be an alternative.

2.10 A Method for Scheduling Integrated Transit Service

Hickman and Blume take both passengers and operators objectives into account, by explicitly inserting the transit agency cost as well as the passenger level of service in the model. The goal in scheduling vehicle trips is from the operator's perspective to minimize the total cost of the service, while it from the passengers' perspective is to maximize the level of service; i.e., minimize travel time, transfer time and the number of transfers. But in this case we only focus only on the passenger level of service.

In the model formation we take the fixed route (LRT) schedule and passenger pickup and drop off point. This pickup and drop off points are selected point of major taxi station and LRT stop points.

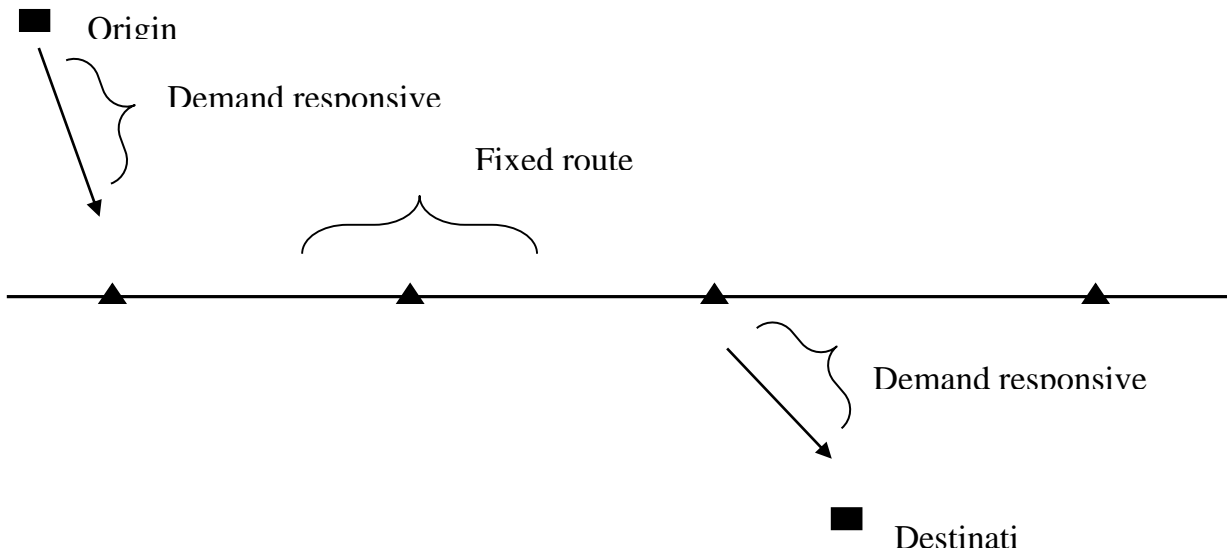
Using this information, the proposed technique determines which trips are eligible for integrated service using the passenger level- of-service constraints. A schedule is then created for both the passenger trips and the vehicle trips in the integrated service, so that the total cost of service is minimized.

Development of integrated transit

- i. scheduling passenger trips and
- ii. scheduling vehicle trips

In the scheduling of passenger trips, an itinerary is developed for each integrated service request in which scheduling passenger trips in pure integrated service the total travel length of the passenger is covered by demand response and fixed route service. This service is done by the following step.

- A demand-responsive vehicle may pick up the passengers from their origin and “feed” them to an appropriate fixed-route stop.
- A fixed-route vehicle will then pick the passenger up and transport him/her to another fixed-route stop.
- A second demand-responsive vehicle may carry the passenger from the second fixed route stop to their destination.



■ origin and destination

▲ possible transfer point

Figure 8: An integrated transit trip

First, one must find a feasible passenger itinerary, connecting the passenger's origin with the passenger's destination with transit service that maximizes the passenger's level of service. If such a passenger itinerary can be found that meets these level-of-service requirements, the passenger's trip is scheduled. Second, the demand responsive trip legs must be added to a vehicle's schedule.

The following (typical) inputs for these two scheduling tasks are assumed

- the location of the passengers' pickup and dropoff points
- the passenger's requested times in which pickups and dropoffs must occur
- the location of fixed-route stops
- the schedules of all fixed -route vehicles

-
- the time windows in which demand vehicles are permitted to meet fixed route vehicles at transfer points
 - vehicle capacities
 - the distance between stops

Passenger route Development

In the first stage, the potential passenger trip from the origin to the fixed route, on the fixed route, and from the fixed route to the destination is scheduled.

To develop an integrated itinerary, a passenger is selected and locations are identified. The origin and destination point are identified. The Euclidean distance between the origin and destination is calculated. This distance must exceed some specified minimum distance; this screening is done to eliminate an inconvenient pair of transfers for very short trips. Then the distance (network distance) will be calculated by assuming only demand responsive route. The entire available route on fixed route will be searched; if the route is found then the distance is calculated. Then the distances, those who use only demand responsive and those who use the combination will be compared and the shortest distance will be selected.

For each such route, a passenger's level -of -service measure must be evaluated. The passenger level of service is measured by calculating the sum of travel and transfer time along each path. The fixed-route schedules give an estimate of travel times on the fixed-route service; and, in- vehicle travel times for the demand response trips are obtained from field data.

The path with the minimum generalized time is then compared to the generalized time of a direct taxi trip (the baseline). The approach in the case study assumes that the existing taxi service is the "default" or "baseline" service, should it prove infeasible to serve the trip with the integrated service.



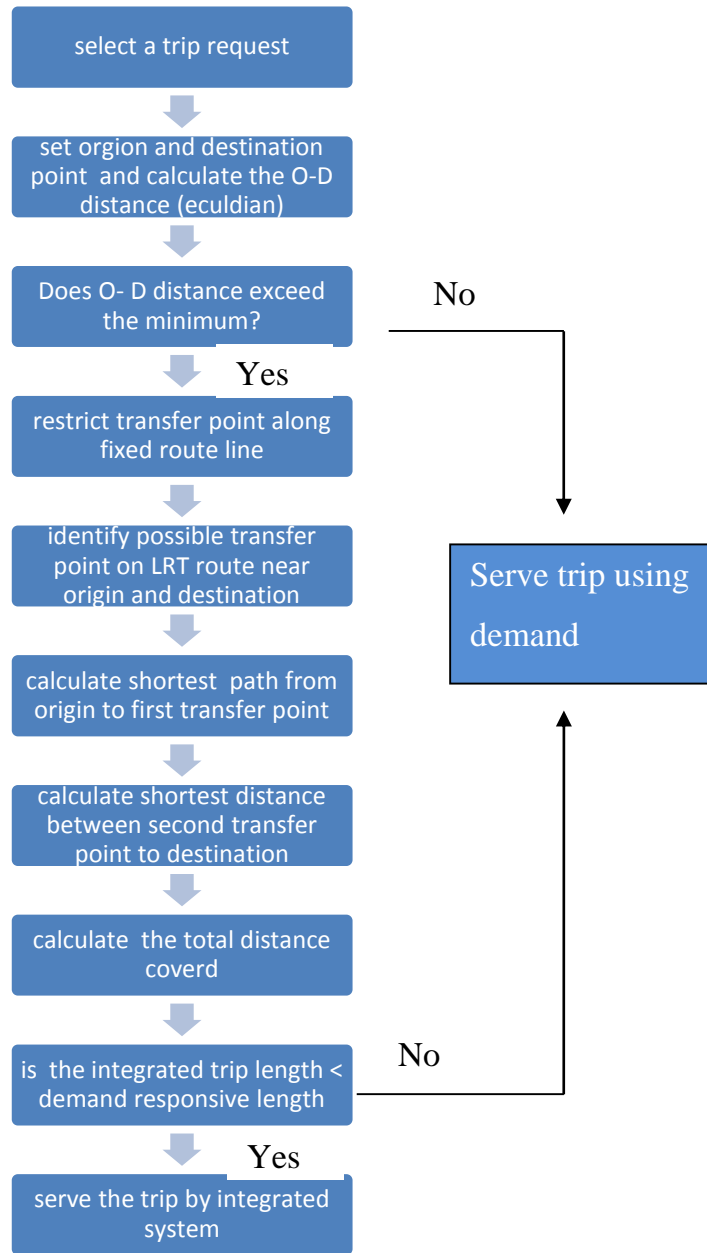


Figure 9: Passenger route development

2.11. Determining the required number of vehicles

DRTS involve assigning vehicles to satisfy demands from a set of passenger who request operators to pick them up from specific locations and deliver them to specific destinations. Let $L(A,B)$ be a random variable from the latter distribution, representing the distance between point A and point B.

2.11.1 The expected number of vehicles

We have a list of n requests scattered in a service area. Our objective is to estimate the number of vehicles needed to serve these requests.

Let r_m be the probability of serving a set of m requests out of the n total requests with the same vehicle. Each request can be satisfied if assigned to a vehicle ($r_1 = 1$). If for example we state that each vehicle cannot serve more than two requests, then there will be on average $n/2 r_2$ vehicles that serve two requests and $n(1-r_2)$ that serve the remainder. The expected total number of vehicles $E(z)$ needed to serve n requests is then

$$E(Z) = n/2 r_2 + n(1-r_2)$$

If now we suppose that each vehicle can serve three requests, there will be on average $n/3 r_3$ vehicles that serve three requests, $n/2 r_2 (1-r_3)$ that serve two requests (where $r_2(1-r_3)$ is the joint probability of serving two requests with a vehicle that could not serve three of them) and finally $n(1-r_2)(1-r_3)$ that serve only one request. Thus, the expected number of vehicles is

$$E(Z) = n/3 r_3 + n/2 r_2 (1-r_3) + n(1-r_2)(1-r_3)$$

The expected number of vehicles needed to serve n requests can be computed generalizing the above equation:

$$E(Z) = n \sum_{i=1}^n r_i / i \prod_{j=i+1}^n (1-r_j)$$

It can be noted that the succession of the probabilities r_1, r_2, \dots, r_n rapidly converges to zero so that we need to determine only the first m values. In the next section we will discuss how we can estimate the values of r_2, \dots, r_m .

2.11.2 The probability of serving m requests with one vehicle

If one vehicle has to serve m requests it will have to visit $2m$ nodes (m pickups and m deliveries). Let us focus our attention on the easiest case, that is for $m = 2$. We want to compute the probability of success in serving with one vehicle any pair of requests (say, 1 and 2) among the n requests waiting to be served. The vehicle must then visit four nodes: the pickup and delivery point of the first and of the second request each one having the above defined time window. We will indicate these points with P_1 , D_1 , P_2 and D_2 respectively. The feasible sequence is $P_1 D_1 P_2 D_2$ (we can serve first P_1 and then D_1 , D_1 and then P_2 , and P_2 and then D_2)

Since we assumed that the location of any point is not related to the location of all the others, the travel times of these three events are independent. However, the arrival time to P_2 is dependent on the travel time of the first two legs. In order to simplify the computation of the joint probability of the realization of the above sequence (i.e., P_1 to D_1 to P_2 to D_2) we assume that it is the product of the probabilities of the single events. This assumption of independence of the events related to a sequence overlooks the links between the arrival time at a node and the departure time from the same node. It is likely to be a more severe limitation as the time window width decreases and the vehicle is running late. The total time window includes waiting time at both end (at pickup and at) delivery and total travel time travel time.

3. METHODOLOGY

3.1 Study Area

Addis Ababa is the capital and the largest city of Ethiopia and it is the country's commercial, manufacturing, and cultural center and has an expanded area of over 540 sq.km and is situated at an altitude of about 2500 meters above sea level. Administratively, the city is subdivided into 10 sub cities and 99 kebeles. Addis Ababa is also an unofficial capital city of Africa, largely due to the fact that it hosts various international organizations. In Addis Ababa city a new light rail transit is just under completion. The total length of the LRT is 34.2 km with the direction of operation of North-South and East-West with respective length of 16.9 km and 17.35km.

The case study for integration public transport system is from Ayat to Meskel Square which is a portion of the East-West network with a length of 12.2 KM.

3.2 Data collection methods

In an integrated service combined by different modes, one must also consider the problem that different modes can perform different parts of the same journey. So when planning an integrated service, it is important to consider the demand of the customer and the response by the service provider.

This thesis tries to demonstrate facts and findings by using (data and information) as primary and secondary sources. The secondary data was mostly obtained from such sources as published and unpublished documents collected from pertinent institutions as the City Bus Enterprise, Addis Ababa City Roads Authority, Taxi Associations and different research papers studied in the area.

The primary data is conducted in the corridor from Meskel Square to Ayat and in this area ten major count stations were selected. The modes of transport in this area are Anbessa city

bus, higer bus and minibus. Since the objective of the research is to create seamlessly integrated service between LRT and minibus (taxi), we collected number of passengers carried by taxis and travel time of taxi in the network.

Minibus is privately owned transport service provider in the city with a capacity of 12 passengers. Unlike Anbessa bus we cannot get organized and recorded data of passengers traveled by these vehicles. Therefore, the numbers of passengers have to be counted at selected taxi stations. These taxi terminals are served as loading and unloading place for taxis and higer buses. The counts were conducted for seven days at peak hours. There are basically two conditions at the terminals; the one which has a long queue of passengers, due to lack of adequate service, and the others which have a long queue of taxis due to excess provision of taxis. In order to have actual demand data of the taxi users, for the first case we counted the number of arrival passengers within one hour and for the second case, which has taxis queue, we counted the number of taxis leaving with passengers and multiplied by the number of passengers who is supposed to be travelled in a given taxi. The selected terminals for taxi data are Meskel Square, Kasanchis, 22 Mazia, Megenagna, Aratkilllo, Bole, Gerji, Paisa, Ayat and Semit. The summary of collected data is provided in appendix 1.

3.3 Study strategy

In order to conduct this thesis, the first step is done by assessing the current performance of public transport services in Addis Ababa by collecting secondary data and by reviewing previously done papers on performance of public transport. After identifying the problems and the gaps, the next step was done by identifying routes for demand responsive services on existing networks. The network for the vehicle was designed by using transport planning software called TRANSCAD. The determination of the number of this service was done by using Microsoft Excel by putting all the necessary inputs. The case will be set by assuming light rail transit as a main fixed route and minibuses as feeder transport services to the rail transit.

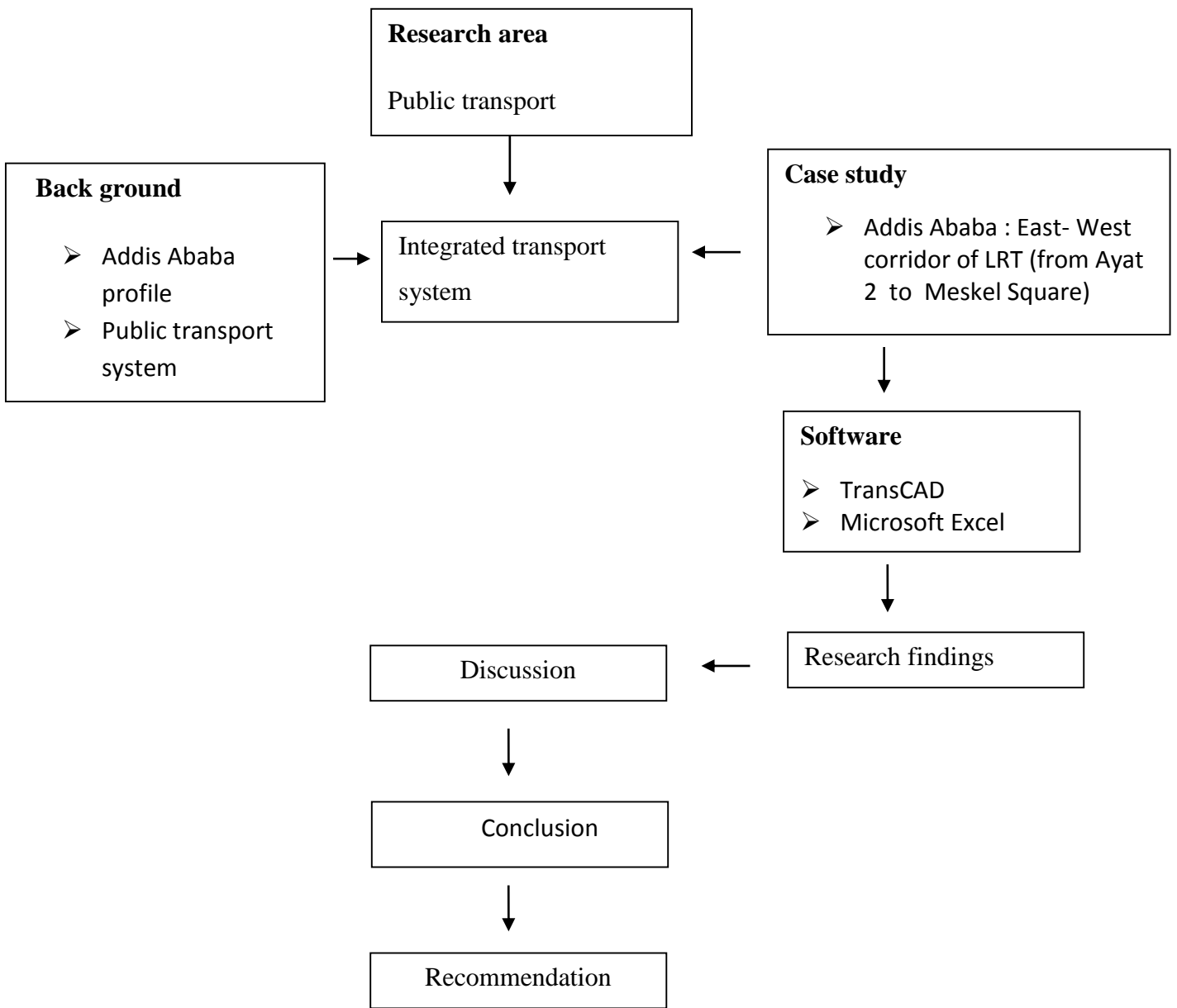


Figure 10:Research methodology chart

3.4 Method of data processing and analysis

When designing and evaluating an integrated public transport service one need a planning tool. One such tool is the TransCAD that will be described here.

3.4.1 Description of Trans CAD

TransCAD is the flexible and capable travel demand modeling software. TransCAD supports all important styles of travel demand modeling including sketch planning methods, four-step demand models, activity models, and other advanced disaggregate modeling techniques, and comes with the most extensive set of traffic assignment models ever assembled for use by planners and traffic engineers.

TransCAD integrates geographic information system (GIS) and demand modeling capabilities. There are many reasons why it is valuable to have a GIS as an integral part of a travel demand forecasting package. First, GIS makes it possible for planning models to be much more accurate. For example, network distances are based on the actual shape of the road network and a correct representation of highway interchanges.

Second, the whole modeling process is more efficient. Data preparation is greatly facilitated and the database and visualization capabilities catch errors before they cause modeling problems.

TransCAD has native support for ESRI Personal Geodatabases, Access, Excel, and Google Earth. TransCAD can import data from virtually all major GIS, CAD, and planning software packages. TransCAD can export data in ASCII, Shapefile, DXF, and Oracle Spatial formats.

3.4.2 Transit Networks and Paths

TransCAD has special tools and procedures for creating and working with transit networks. Using transit networks, we can solve shortest path problems, calculate transit path attributes (i.e . skims), and perform transit assignment. In this thesis TransCAD is used as transit path finder by solving shortest path problems. The shortest path will be determined among different available road network in the area.

3.4.3 Input to TransCAD

The road network consists of a set of nodes and a set of directed links connecting the nodes. The nodes and the links are defined in separate files. The nodes file contains only information about the coordinates of the nodes. The links file contains information about which nodes the link is connecting, the length of the link and the link speed. The model of the road network is used both for estimating travel times and for routing vehicles.

3.4.4 Output from TransCAD

From TransCAD we can get different travel statics contain the most interesting information when evaluating an integrated service. Included here are, for example, the total numbers of passengers carried and journey-legs completed, with average travel times and distances.

4. ASSESSMENT OF CURRENT PUBLIC TRANSPORT SERVICE IN ADDIS ABABA

4.1 Introduction

Ethiopia profile

Ethiopia, is a large size country, located in the eastern part of Africa between latitude 30-50N and longitude 330-480E. The geographic area extends over 1.25 million sq. km. The country includes 11 regions. The population size is estimated to be 73.75million (2007) and estimated to reach 93 million by 2015. The population is growing at a rate of 2.92 per annum. Based on population censuses in 2007, the number of people in urban center was 11.86 million which was 16.08%.

Agriculture is the main economic base contributing 45-50%of the country's GDP, providing 80% of employment and accounting for 85% of export. The contribution of industries is low at 12%. (Source- Consultancy Engineering Services (India) Private Limited in association with Saba Engineering (March 2005) Urban Transport Study and Preparation of Pilot Project for Addis Ababa Findings Report, Volume I)

Addis Ababa profile

Addis Ababa, the 'New Flower' of the nation, founded by Emperor Menilik II in 1887, is the administrative, political, economic and cultural capital city of Ethiopia which is located at the heart of the country. It has an area of 540km² of which 18 km² are rural.

The largest vacant lands are located in the eastern and south-eastern parts. In addition, there are scarcely populated mountain ranges in the north and in the west. The city is dominated by 3,000 meters high Entoto Mountains to the north. Addis Ababa is cut by a number of rivers flowing generally from north to south, all of them being tributaries of Great Akaki River or Little Akaki River flowing to Lake Aba Samuel just outside the southern border of the metropolitan area.

Addis Ababa depends on its transportation system for its existence. The system permits people to reach work, school, health and social services, shopping, recreational, and

cultural and sports events, visit friends and family. It allows employers to access a supply of labor and goods to be sent and received in the course of domestic and international trade. Public transport in Addis Ababa is provided by high-capacity buses operated by Anbessa City Bus Enterprise, with a nominal capacity of 100 passengers per bus, in case of articulated bus twice the nominal capacity, minibus with a capacity of 12 passengers and some other types of buses, which is owned by private operators.

The formal bus operator in Addis Ababa, Anbessa City Bus Service Enterprise, maintains detailed records of its passenger carryings on each of the 112 routes that it operates derived from single-trip ticket sales. The study on improving urban transport which was carried out by detailed loading surveys at a limited number of sites and concluded that the share of minibuses and modified taxis were roughly three-quarter of the large buses. However the average trip length on the smaller vehicles is considered to be significantly lower than the buses, and might therefore result in passenger numbers being up to 50% more than the Anbessa City Bus Enterprise.

4.2 Road Network in Addis Ababa

As long as a city exists, the need for road networks is there, even though the extent of coverage might vary. The development of the roads in the city owes its history to the founders of the city, namely Emperor Menilik and EtegeTaitu. History has it that the Emperor himself was at the forefront of the development, even partaking in hard physical labor.

In EC 1894, the Emperor undertook the construction of the roads from Addis Ababa to Addis Alem and from the palace (presently located in the area known as Arat Kilo) to the British Embassy and in many different directions. Even if it wasn't highly successful emperor Menilik brought in rollers (stone crushers) and tried to construct modern roads with the help of local laborers.

Only the roads from the palace to 'Entoto Genet' and Addis Alem were successfully upgraded into modern standards. The rest were doomed to be dusty in the winter and muddy in the summer times. Emperor Menilik, imported 2 vehicles to Addis Ababa in 1899 by the

end of his reign. However, up to EC 1912, movement in and around the city was limited to mules and horsebacks with most of the roads being nothing more than mule trails. Better and modern road construction did not materialize in Addis Ababa until the era of Emperor Haileselassie I. It was during his reign that road construction began to be undertaken in a modern and extensive manner. During this time a new office, ‘The Public Works Department’ was set up, with the objective of constructing new roads and upgrading the existing ones in and around the city of Addis Ababa.

The department was upgraded to a ministerial level and the city developed its own organization henceforth.

The following table shows road net work coverage i.e. asphalt roads, gravel/ dirt roads, pedestrian walk ways and drainage lines in Addis Ababa

Table 2: Constructed vehicular road coverage

Road Hierarchy	Length of Varying width (Km)	Length in terms of 7m width (km)	No of bridges	Condition
Arterial	250	336	93	Good
Sub Arterial	95	133	34	Good
Collector	151	181	44	Good
Local	167	167	30	Good
Total	336	817	201	Good

Source- Addis Ababa City Road Authority

4.3 Structure and Organization of Urban Public Transport

Anbessa City Bus Service Enterprise provides the conventional bus services in Addis Ababa. Although the Federal government owns this company, its operations are financially supported by the City Administration that pays a subsidy for each passenger carried.

However, the level of such subsidies is gradually being reduced and the formal linkage to passenger numbers has now been broken. The resulting removal of the performance incentive is undesirable, even if it allows for easier budgeting at the City Administration. Anbessa was originally a private enterprise holding an exclusive franchise for the provision of passenger transport services in the city, but was nationalized in 1974. It then formed one part of the Passenger Transport Corporation (PTC), with two other divisions being responsible for long-distance bus services and bus materials (spare parts and bodies) supply respectively.

In 1996, PTC was divided into its three offices, and Anbessa was established again as a freestanding commercial enterprise. Since then, the workshops component of Abay Technical Services (the bus materials supply division of PTC) has been merged with Anbessa, with which it shares the Yeka Depot Site. This latter business provides services both to Anbessa and to the external markets.

Anbessa operates out of three sites, its headquarters complex at Yeka to the east of the city, a second depot at Shegole northwest of the city, and a newly opened depot at Mekanisa, south of the city.

The Yeka Depot is 7.0 hectares in area, excluding the bus-building workshops complex of Abay Technical Services that is immediately adjoining. The operating depot has the facilities for 300 buses to be based there, but currently only 221 are deployed. The site also includes the central workshops for the enterprise and the main spare parts warehouse. The headquarters office provides both for central administrative and depot control functions.

The second depot at Shegole is 5.4 hectares in area, but the yard is not surfaced. This facility has its own fuel station, and light maintenance and running repair facilities as well as a spare parts store operated on a satellite basis from Yeka. The number of buses could be based here is 300, but at present only 171 are deployed.

The third depot at Mekanisa has only recently become operational. It has a site area of 7.3 hectares, which would be more than sufficient to handle 300 buses; however only 73 are deployed at the moment. Facilities are being developed with the intention of making it self-sufficient. The major outstanding investment need is for the yard to be surfaced.

The informal sector in Addis Ababa provides minibus and ‘modified taxi’ services throughout the city. The latter vehicles are pick-ups converted to passenger carriage by the addition of a canopy over their load bed, fitted with bench seats and windows on each side with passenger capacity of 12 persons, excluding other than the driver by regulation.

Minibus services can be regarded as high quality in comparison with conventional buses, as their interior layout is spacious (10 seats in the main saloon, compared to a minimum of 12 in most other jurisdictions) and over-loading is rare over most of the network. However the condition of the seats and cleanliness of the interior often leave much to be desired.

Modified taxis tend to operate on poorer and unmade roads, and serve market areas where the carriage of produce as well as people is important. Their seating is much more cramped than for the minibuses, and the carriage of produce often affects odor and cleanliness. They are also generally older than the minibuses, having been developed locally to meet emerging demand at a time when minibus imports were not possible. These modified taxis are currently out of service.

Ideally, the private sector should provide both commercial bus service, complementing the subsidized network of Anbessa, and a range of premium products designed to segment the public transport market and proving capable of attracting car users. Existing minibuses are too small for the former role and may not be sufficiently comfortable for the second.



Figure 2: Buses and Minibuses in the city

4.4 Operational Characteristics

4.4.1 Routes operated

At the moment Anbessa operates 108 of its 112 designated routes, with Routes 1, 22, 86 and 91 being suspended. The services are provided throughout the operating day, nominally from 06.00 to 22.00 hrs. Nine of these routes are peri-urban, connecting settlements outside the city boundary that fall within the travel-to-work area. The balance provides services within the city, mostly on radial routes to the central business and commercial areas of the city.

On 25 of these routes there are supplementary peak services operated according to vehicle availability, with only 6 of these receiving a regular vehicle allocation. The peak services are usually run over a shorter portion of the designated route, but still charge the same fare as for the full service. In this manner, they help to provide a more accurate match of transport supply to passenger demand.

A high proportion of the routes are operated to the three main terminals of Anbessa: Addis Ketema (Merkato) (33 routes); Leghar (22 routes); and Menelik Square (9 routes). Another

7 interchanges are also used, covering 46 routes, but most routes originate from street-side facilities in the suburbs.

Transport Authority estimates that there may be as many as 300 route segments, but has not carried out a detailed analysis. The Authority has been doing zoning system for each minibus since 2004E.c. Until this system has started, minibuses can operate wherever they want along the route. The previous system did not depend on the demand side of but on the desire and benefit of the drivers.

Allocating minibuses into different zones provide a better quality in the system by giving balanced service. But due to lack of detailed study of demand of the society; it can't solve the problem as it supposed to be. As seen in most areas, there are a long queue of people and in some places there are long queue of minibuses.

only one. The nine peri-urban services are operated at headways ranging from one half to three hours.

Minibus taxis do not operate according to scheduled timetables. Rather, the practice in the industry is for each vehicle to wait in line at its terminal until it has been filled ('fill and run') and only then to commence its operation. This can provide a good level of service throughout the day on more busy routes, but often results in excessive waiting time in the off-peak period for quieter routes.

4.4.3 Vehicle Kilometers Run

Anbessa has a peak vehicle requirement for its core services of 344 buses. Some 1.82 million kilometers per month were run by these buses, representing 176 kilometers per bus per day. Primary control of the route network is carried out at the three main terminals; Addis Ketema, Leghar and Menelik Square. Terminal controllers adjust services as required to balance the implications of late arrivals and lost trips, and re-allocate vehicles accordingly in order to meet the most pressing levels of demand.

Obtaining estimates for minibus kilometres is not at all easy. The drivers don't think in terms of kilometres, but rather in terms of the fuel they use (litres) or the cost they incur (Birr). The drivers indicated daily utilisation over the wide range of 50 to 160 kilometres, with route lengths of 6 to 10 kilometres.

4.4.4 Terminal management system

The bus terminals are congested, and poorly laid out to deal with the volume of bus movements and the high number of routes being operated through them. The study on improving transport recommends that any development of their facilities should be delayed pending restructuring of the route network in response to a scientific travel demand study. Revisions arising from this would probably result in more routes being run through the city centre, and less actually being terminated in it.

Minibus terminal management is provided by self-appointed teraaskebari, literally taxi-order attendants. The urban transport study reports that the marshals have formed into informal ‘community co-operatives’ or ‘unions’ based on terminals. Minibus drivers make payments to the ‘teraaskebari’ per departure. Charges are between Birr 1 and 2 per departure.

4.5 Identified Problems

4.5.1 Shortage of Service Providers

The provision of buses and minibuses are not enough to satisfy public transport in the city. In order to minimize this, Anbessa city bus has imported new buses around 550 out of this 200 buses are articulated, which has the capacity of twice as much as the normal buses. The buses that were assigned in each route didn’t serve as scheduled due to many problems. According to the report of Study of urban public transport conditions in Addis Ababa, 73% of the buses has come late, which is beyond the proposed time schedule.

In case of taxis, since the new system was implemented, it has not satisfied the needs of all users. For example in some areas, there will be along queue of people and in the reverse there will be a long queue of minibuses waiting for their turn, especially at peak hours. According to the survey, sometimes waiting times reaches to 20min.



Figure 4: Long queue of passenger around bole

4.5.2 Low Levels of Safety

The real safety issues with regard to urban transport relate to pedestrians. In order to have safe pedestrian movement, there should be provided with adequate pedestrian cross walks

provide. In most of Addis Ababa roads, where sidewalks are provided, it is occupied by parked cars and road side sellers which are obstructing movements of people and forcing them to the roadway. Road crossings are also problematic, with few signalized junctions having adequate pedestrian provisions, but the rest are unsignalled crossings mostly ignored by motorists; there are very few pedestrian over-bridges and underpasses. Further problems exist at public transport stops and terminals, with inadequate isolation of movements and little consideration being given by drivers.

4.5.3 Poor Service Quality

Most of the problems encountered in the case of a minibus service is overloading. The nominal capacity of minibus is 12 passengers; but during peak hour they load up to 17 passengers.

Regarding the quality of service, the Anbessa City Bus Service has to do a lot of works. According to the interview passengers identified passenger crowding on buses as bad and they also stated this overcrowding exposed them to minor crimes.

The study on improving transport and the urban transport study commented on lack of facilities provided for passengers, both at the terminals and at stops along the routes. Even the main terminals lack adequate toilet facilities. Only a very small proportion of the 900 bus stops have any form of shelter, and these have not been incorporated into even the recently constructed interchanges.

4.5.4 Poor service accessibility

The study on improving transport found that the shorter walking distance to a stop was a factor in their modal selection for 60% of minibus passengers, and that 90% of passengers indicated that there was no available bus service to their destination.

The accessibility of minibuses is better than that of the buses in city centers but in outer suburban areas bajajs (3 wheel vehicles) and animal modes are serving to facilitate access to the pre-urban service.

4.5.5 Inappropriate vehicle type and size

Public transport in Addis Ababa is provided by high-capacity standee buses, with a nominal capacity of 100 passengers for normal bus and around 200 for articulated bus, minibus with a capacity of 12 passengers and some other types of buses (Higer with a maximum capacity of 60). This Higer bus is small in number and operates in some selected routes (most of the time connecting suburban areas).

The fact that there are no many urban buses offering a passenger capacity of between 12 and 100 is a direct consequence of two regulatory decisions. Although Higer bus allowed providing urban transport service, its service is limited to some areas.

4.5. 6 Lack of Integrated Network Design

Design of public transport networks is usually based on a deterministic point of view: it is assumed that all components of the system perform as planned. In reality, however, there are a large number of regular and irregular variations influencing public transport services such as variation in demand, service operation, and infrastructure availability.

The propagation of routes within the Anbessa network has arisen through an unintended consequence of price controls. The fare charged for any journey is the fare applicable to that route, not to the distance of travel by the passengers. Authorized fares can only be raised when a route is redesigned or extended, or a new route is created. This system has provided an incentive for Anbessa to construct a complex network with a high degree of overlap between individual routes. Each of these routes is then run at a relative frequency of services, and fares on the common sections may vary significantly.

Similarly for the minibus sector, route fragmentation is an unintended consequence of a poorly designed fares structure. During peak hours breaking up routes into shorter sections are common trends in the case of minibuses to get additional fares.

5. CASE STUDY: Addis Ababa from Ayat II to Meskel Square

5.1 General

In this case study, the integrated transit network for demand responsive (taxi) and fixed transit system (LRT) will be designed based on the process which is described in chapter three for the East-West direction of LRT route from Ayat to Meskel square, in this regard and the number of taxis in the route will be estimated.

5.2 Background

The Addis Ababa LRT covers the East-West and North-South transport corridors. The East-West Line extends from Ayat to Tor Hailoch with around 17.35km and the North – South Line is extends from AradaGiorgis to Kaliti with 16.9km. The total length of these two corridors is 34.5 km.

The East-West corridor passes through the city center from the eastern peripheries of the city to the west. The East-West corridor is presumed to serve suburban in from the Oromia Region such as Legetafo in the East and Sebeta in the West.

Major residential and real estate development locations at Ayat, CMC, Gurdshola and the area west of Torhailoch are accessed through this route. Meskel Square is the major public gathering location in Addis Ababa and Meganagna Square is an important transit hub and commercial centre. The East-West corridor crosses the Ring Road twice at Meganagna and Torhailoch.

The *East-West route* will serve the following major locations:

- Ayat village real estate development area;
- CMC real estate;
- Civil Service College;
- Gurdshola residential area;

-
- Megenagna junction where overpass bridge, tax/bus bays, and the Addis Dessie highway interface;
 - Lem Hotel Junction (residential and business area);
 - Hayahulet junction (residential and business area);
 - St. Urael Church Junction, recently being a prominent business area;
 - Bambis junction (residential and business area);
 - Meskel Square, the biggest square in Addis where political & social gatherings, religious festivities and exhibitions take place. Six major streets coverage at this Square;
 - The national stadium adjacent to Meskel Square, where football fans gather
 - La Gare, where the Ethio-Djibouti railway line formerly terminated and where the Anbessa City Bus Station is located;
 - Mexico Square, where six major streets coverage;
 - Lideta, an important business and religious gathering takes place; and
 - Torhailoch, an important link to the vast western suburban area and an important link to the Addis Ababa-Jimma Road via the ring road.

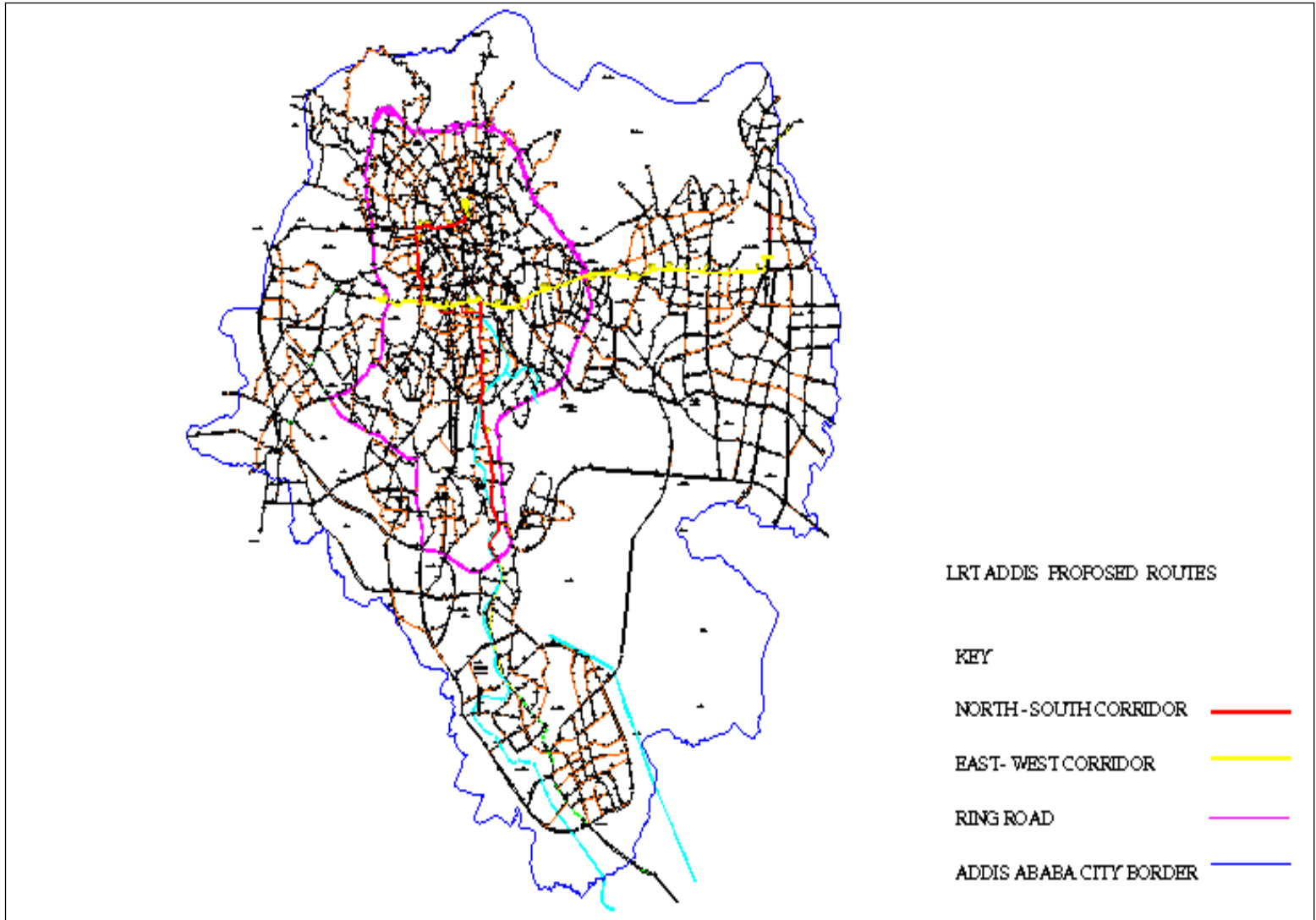


Figure 5: LRT Addis proposed routes

5.3 Route Descriptions

The East-West Line passes through the center of Addis Ababa connecting the major road junctions and locations at Ayat, Megenagna, Urael, Meskel Square, Mexico Square, Lideta and Torhailoch. The major transfer point along this corridor are Megenagna taxi/bus station and Meskel Square. In addition to these major connection points, there are other stations where heavy traffic flows are anticipated such as Torhailoch, Urael, Hayahulet and Ayat. Minor stations are Ayat, CMC, Gurdshola, Lemhotel, hayahulet, St. Urael church and Bambis, and are shown in figure 15.



Figure 6: East West direction stations

5.4 Converging Points

Converging points are places where the demand responsive vehicles and fixed route transit meet physically. Normally, there are many practical details to be taken into account when deciding the number and location of meeting points. In this case, the first criteria for selecting these points are the physical connection between the fixed route and demand responsive routes.



Figure 7: Physical connection locations between LRT and demand responsive routes

5.5 Operating characteristics

The main public transit services operating along the study area:

-
- Anbessa Bus;
 - Medi buses (commonly known as Higer buses);
 - Mini bus taxis; and
 - Other types of privately-operated buses.

The Anbessa buses are 100 passenger capacity large buses providing public transport services for no profit. The Medi buses are commercial buses owned by private individuals or companies. They have a capacity for 25 seated and 10 standing passengers.

The Mini Bus taxis with a 12 seat capacity nearly transport 50% of the total passengers along the corridor.

According to feasibility study of LRT, the following data is provided on East-West corridor

- **Anbessa Buses:** There are at least 31 routes along the corridor and they transport some **49,450** passengers per day.
- **Medi Bus routes (Higer Bus):** There are 27 routes and they transport some **251,577** passengers per day.
- **Mini bus taxis:** there are 1,160 minibuses in each route, with 12 seat capacity transporting **258,325** passengers each day.

By its first years of full operation of LRT (with 41 LRV of each 286 capacity for an operation of 16 hours per day at an average speed of 21.6km/h) it is expected to perform attract up to 4.05 million passenger kilometers per day. By year 2025 (with 82 LRV of each 286 capacity for an operation of 16 hours per day at an average speed of 21.6km/h) is estimated to perform 8.10 million passenger kilometers per day. It will offer an initial headway of 6 minute service frequency during the peak period and 10 minutes off peak period.

5.6 selected stations

Since the LRT project has two corridors serving the entire city from south to north and from east to west, it would be difficult to consider the entire city for the study. Therefore it was found necessary to select some area. The selection is based on the LRT corridor from Ayat II to Mekel square.

The selected area was further divided into 10 count stations. While delineating these stations, it was tried to make each zone homogenous as much as possible with respect to land use and the other criterion was based on centroid. The centroid in each area was taken from main taxi stations.

The number of departures from each origin and arrivals to each destination and speed characteristics of the network, are the major data that has been collected at each station. The collected data is attached in Appendix 1

The selected stations are Meskel Square, Paisa, Aratkilllo, Aware, Kasanchis, HayahuletMazria, Megenagna, Bole, Imperial and Gerji.

5.7 Demand

The Number of public transport users varies under different providers like months of the year, days of the month and hours of a day. Therefore while conducting the survey demand it was found necessary to consider this variations. According to feasibility study of LRT volume I the demand variations are as shown below.

Table 3:Hourly distribution of demand

From (hour)	To (hour)	Approximate Percent of Trips in the Corridor
0:00	4:00	0.0%
4:00	6:00	2.0%
6:00	9:00	30.0%
9:00	12:00	10.0%
12:00	13:30	10.0%
13:30	15:30	10.0%
15:30	21:00	32.0%
21:00	22:00	4.0%
22:00	24:00	2.0%
Total in 24 hours		100.0%

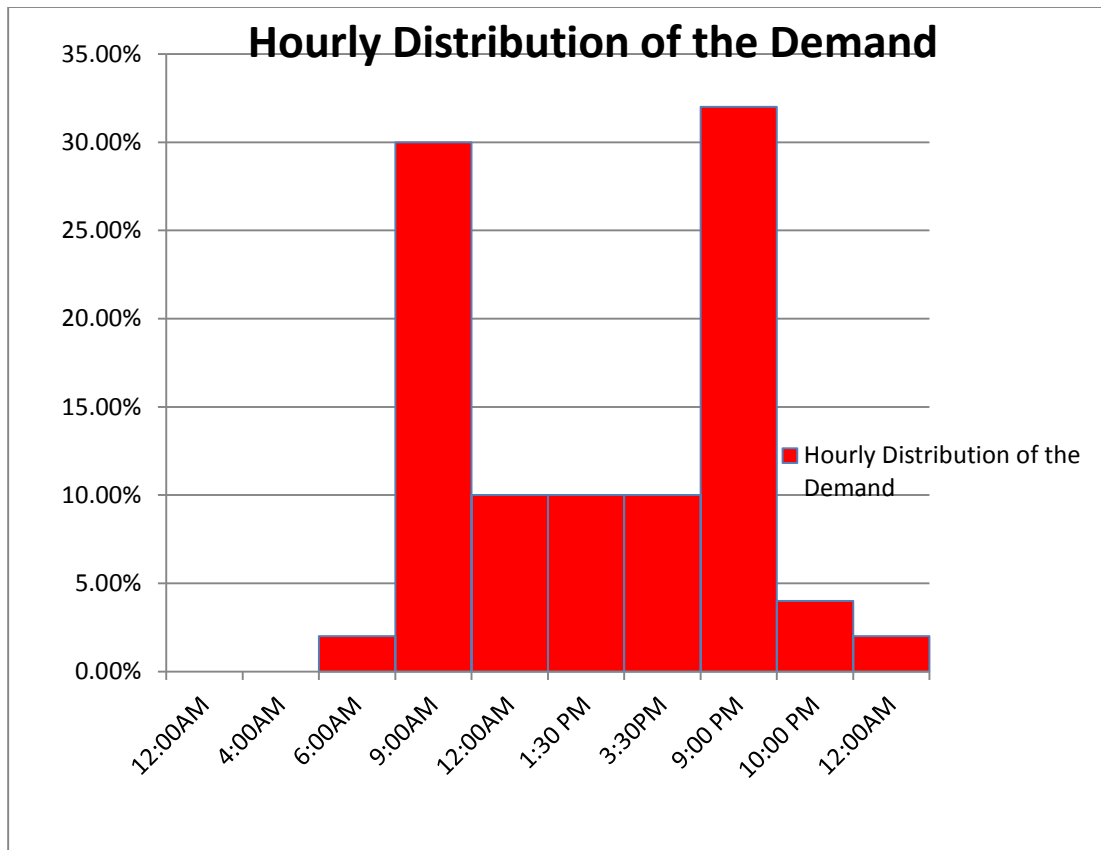


Figure 8:Hourly distribution of the demand

As we can see from the above table and chart the morning peak hour is from 6:00 AM to 9:00AM (12:00-3:00 local time) and afternoon peak hour is between 3:30 PM and 9:00 PM (9:30-3:00 local time). Therefore, the survey were conducted on morning peak hours and afternoon peak hours which were then converted to off peak hour by multiplying the percentages of the duration on table 3. In order to determine the variation factor of days in a week, the count was done on weekdays (from Monday to Friday) and weekends (Saturday and Sunday) separately.

6. ANALYSIS AND DISCUSSION

6.1 General

Using the proposed methodology, the integrated service was compared with the existing fully demand-responsive service, using performance measures of the total number of trips served and the passenger level of service (travel time, waiting time and transfers time).

6.2 Inputs

In order to develop an integrated itinerary, first origin and destination points were identified. In this regard, the Euclidean distance between the origin and destination is calculated. This distance must exceed some specified minimum distance. This minimum integrated trip length of passenger's between origin and destination must be at least 2.5 km apart in order to be considered for an integrated trip. This 2.5 km is taken from the minimum distance that taxis are currently operating per day. Shorter trips are more likely easily served through a direct demand responsive service trip. This screening is done to eliminate an inconvenient pair of transfers for very short trips.

Then, the distance (network distance) will be calculated by assuming only demand responsive routes (base condition of taxi serving routes). The next step will be identifying available transfer point near the origin and destination. From different transfer points, the shortest distance from origin to first transfer point and from second transfer point to destination will be determined. Then the total distance (distance covered by taxi and distance covered by light rail vehicle) will be determined. Once we got the total distance, the travel time for the trip will be computed on excel. Travel time of demand responsive vehicle is conducted during traffic count and the travel time of the light rail is determined from operational speed of light rail vehicle.

Due to lack of data and research conducted in this area, we are forced to use some global parameters.

Origin and destination time windows: 5 minute time windows were used for pick-up at the origin and drop -off at the passengers' destination.

Maximum waiting time at a fixed -route stop: Ideally, the demand responsive vehicle would arrive at the transfer point at the same time as the fixed- route vehicle. However, to allow some flexibility in scheduling, a maximum waiting time for the taxi passengers was set to at 5 minutes. In other words, when dropping off a passenger, a taxi could arrive to a fixed-route time point up to five minutes before the scheduled arrival of the fixed- route vehicle. Also, when picking up a passenger, taxis could arrive up to five minutes after the scheduled arrival time of the fixed-route vehicle.

Before creating an integrated network in the TransCAD software, the geo reference map of the city in the form of shape file has to be edited using ArcGIS. The shape file includes all the necessary information about the network in the attribute table. This data include pavement width, road category, number of lane, hierarchy, type of surface, travel way, growth rate, travel time and length of each network. The network in this shape file was not connected to one another. Therefore, in order to overcome this problem, we connect the entire network in the ArcGIS. After connecting the network the next step was filtering the network whose surface is paved only because those road types with paved surface will be used only in the network.

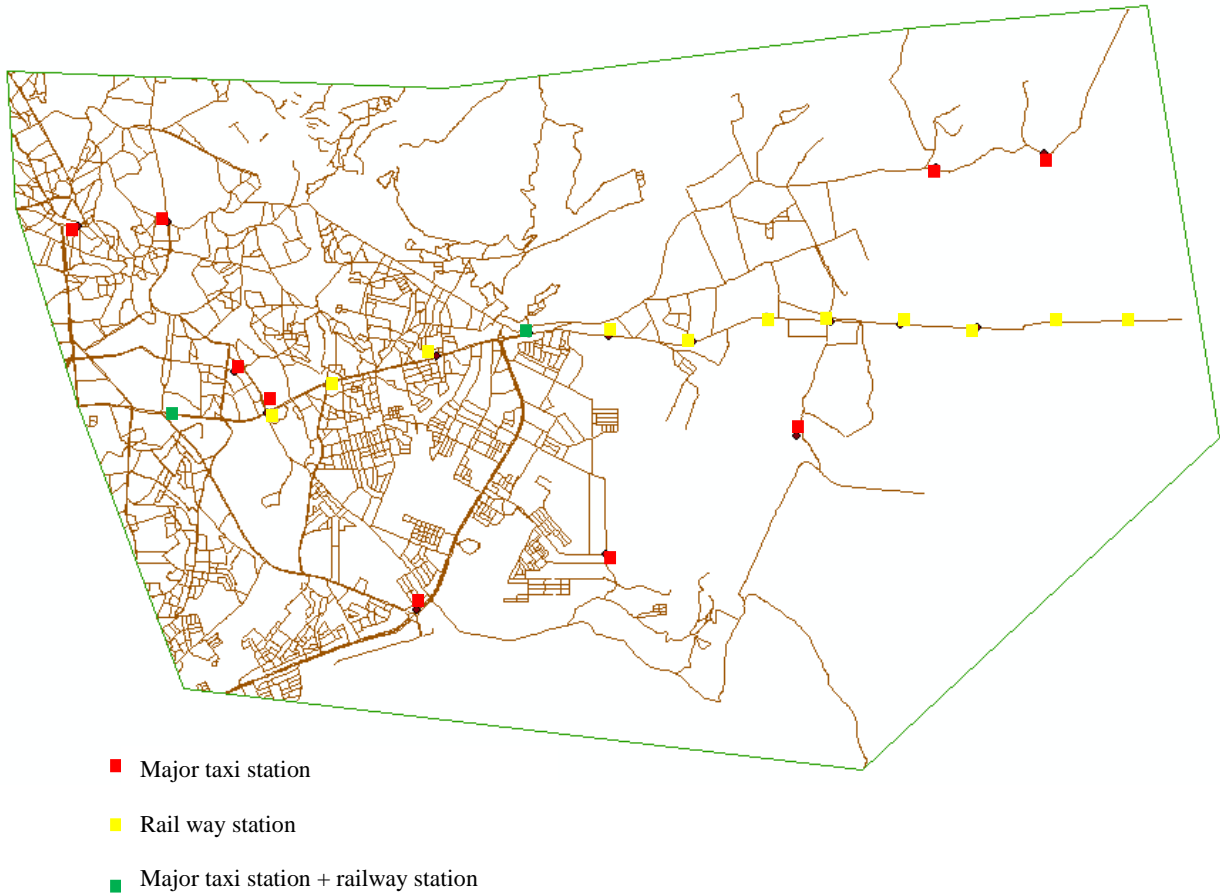


Figure 9: Edited network map in ArcMap

After editing is done on Arcmap, then the network map with the attribute table is sent to Transcad. Based on the figure shown in *Figure 10* Transcad will determine shortest path among the network.

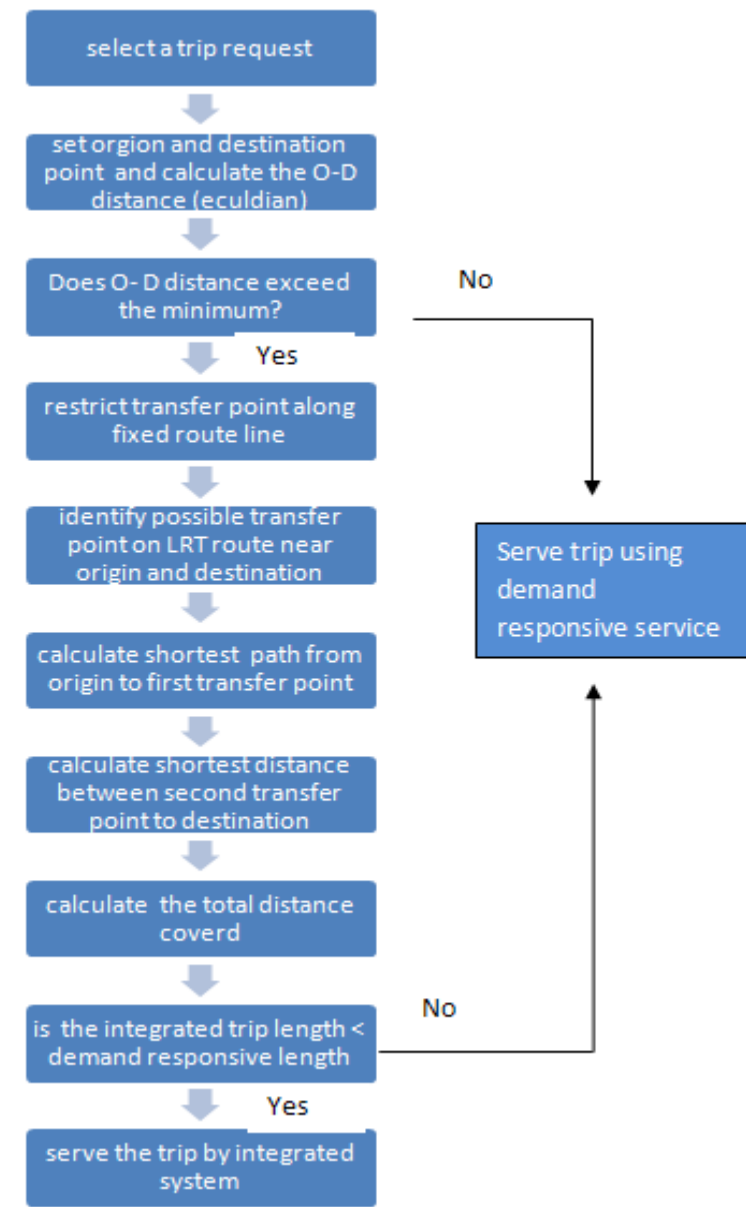


Figure 10: Passenger itinerary development

As it is discussed earlier, the first step is assigning the trip into the network. This process is done on TransCAD. In TransCAD, there are two approaches for finding the optimum route, the first one is based on shortest physical distance and the second one is based on shortest travel time. In this case study the route is selected based on shortest distance. In

the shortest distance method, among the available road network, the optimum route is selected by calculating the network based on distance.

6.3 Example of route development

Among the 34 trips analyzed in the selected area; the one from Kasanchi to Megenagna is selected for demonstration purpose. We have two input conditions: that is peak-hour demand and off-peak hour demand. For illustration purpose in this example we only analyzed peak hour condition. The eculidian distance from Kasanchis to Megenagna is 3.14 km. This eculidian distance is greater than the minimum integrated trip length (2.5 km), which is set by the minimum distance served by taxi in the base condition. Therefore, this trip can be served by integrated trip. The next step will be finding the shortest distance form Kasanchis, which is origin for this trip, to the next transfer point on fixed route. The shortest point on fixed route is found at Urael Station.

In this case, the integrated trip will have two trips; one from origin to the first transfer point by taxi and the other from first transfer point to destination using light rail vehicle. Because the destination of this trip ends on the station of LRT, we don't need additional taxi.

In literature review section, we have seen that there are six different ways of traveling with integrated service. The way of travel for this typical example from "Kasanchis to Megenagna" is shown below.

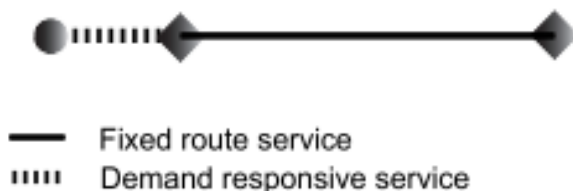


Figure 11: Way of traveling with the integrated service from "Kasanchis to Megenagna"

In the first trip from “Kasanchis to Urael” by taxi have network distance of 0.9 km and have travel time of 4.2 min in the second trip on fixed route the distance is 3.29 km .and have travel time of 2.46 minute.

Therefore, the two integrated trip will result in a total length of 3.36 km and in total travel time of 6.66 minutes. However, since it is integrated trip, it has a transfer point and will result in additional average transfer time of 2.5 minutes. Therefore, integrating of trip will result in total travel time of 9.06 minutes. As for the passenger level of service, the integrated trip described above can be compared with the “baseline”.

Under base condition, the total distance is covered only by taxi. The network distance from “Kasanchis to Megenagna” is 3.94 km and total travel time is 12.78 minutes which is greater than the direct trip served by integrated system. As a result, even with additional transfer time, this particular integrated trip provides the passenger with a slightly better level of service.

6.4 Full analysis and discussion

6.4.1 Physical network integration

In this section we have tried to discuss the result from the full analysis. The “base condition”, which is considered as without light rail transit and all the trip is served by demand responsive vehicle, and the integrated system by considering the light rail transit result from TransCAD software is compared. The comparison is based on passenger level of service (total travel time). Table 5 shows Euclidian and Network distances from origin to destination under base condition.

Origin	Destination	Euclidian distance (km)	Network distance(km)
Meskel sq.	Bole	2.36	2.85
Meskel sq.	Megenagna	5.3	6.27
Meskel sq.	Kasanchis	1.45	1.51
Meskel sq.	4 killo	2.4	2.64
Meskel sq.	piasa	2.46	2.85

Table 5a: Base condition at Meskel Square station

Origin	Destination	Euclidian distance (km)	Network distance(km)
Megenagna	Bole	3.6	3.86
Megenagna	Stadium	5.3	6.27
Megenagna	Piasa	5.39	6.98
Megenagna	gerji	3.04	3.51
Megenagna	22matoria	3.2	3.35
Megenagna	Kotebe,kara	7.06	7.82
Megenagna	Kara, new	7.06	7.19
Megenagna	ayat	7.77	8.54
Megenagna	4 killo	4.37	4.68

Table 5b: Base condition at Megenagna station

Origin	Destination	Euclidian distance (km)	Network distance(km)
Bole	Piasa	6.51	7.5
Bole	4 killo	5.96	7.11
Bole	22Mazoria	3.1	3.39
Bole	Megenagna	3.6	3.86
Bole	Kasanchis	3.8	3.9
Bole	Meskel Sq.	2.36	4.37
Bole	gerji	2.51	3.66

Table 5c: Base condition at Bole station

Origin	Destination	Euclidian distance (km)	Network distance(km)
Kasanchis	Piasa	2.72	3.46
Kasanchis	Bole	3.7	3.9
Kasanchis	Stadium	1.45	1.5
Kasanchis	4 killo	2.26	2.58

Table 5d: Base condition at Kasanchis station

Origin	Destination	Euclidian distance (km)	Network distance(km)
Aratkillo	Megenagna	4.36	4.68
Aratkillo	Paisa	1.05	2.1
Aratkillo	Meskelsq	2.5	2.64
Aratkillo	Bole	6.04	7.11
Aratkillo	Kasanchis	2.26	2.58

Table 5e. Base condition at Aratillo station

Origin	Destination	Euclidian distance (km)	Network distance(km)
Paisa	4 killo	1.05	2.1
Paisa	Megenagna	5.39	6.98
Paisa	Bole	6.51	7.5
Paisa	Meskel sq.	2.46	2.85

Table 5f. Base condition at Piasa station

Origin	Destination	Euclidian distance (km)	Network distance(km)
Gerji	Bole	2.51	3.66
Gerji	Megenagna	3.06	3.51

Table 5g: Base condition at Gerji station

Table 4: "base condition" Euclidian and network distance

In the selected covered area, there are a total of 37 trips made based on the current major taxi terminals. The number of passengers originated from each origin and the number of passenger arrived at each destination and the travel time in each network is conducted based on the method described in methodology part (chapter three).

From the total trips around 78.4% are served by only demand responsive vehicles that travel from the origin to destination. For some trips the case will not be the same as base conditions (the previous route in which minibus were using). Due to the construction of LRT line, the former route is changed because the demand responsive vehicles that will be crossing points on the rail are limited.

Around 13.5% of the trip is served by only light rail transit. This result is due to that the origin and destination of the trip is on the rail station. The entire trip in the direction of LRT line is served by only light rail vehicle. Table 6 show trip that are served by fixed route only.

Origin	Destination	Euclidian distance (km)	Network distance(km)	Travel time in min.
Meskek sq.	Hayahuletmazoria	2.61	3.03	2.71
Meskek sq.	Megenagna	4.90	5.10	3.83
Megenagna	St. Michael	3.32	3.62	2.71
Megenagna	CMC	5.20	5.38	4.04
Megenagna	Ayat	7.57	7.71	5.78

Table 5: Trip served by fixed route only

Around 8.1% the trips are served by combination of demand responsive vehicle and fixed light rail transit to travel from their origins to destinations. The entire trip in this case is served by one demand responsive vehicle and Light rail, either the trip origin or destination is on the station of the light rail vehicle. In this case, we will have only one transfer point from demand responsive vehicle to LRT or from LRT to demand responsive vehicle. On the other case because there is only one line of fixed route, we don't have a trip served by two demand responsive vehicles and the light rail (trip having two transfer points). In this case we will have two transfer points one from origin to fixed route and the other is from fixed route to destination. Table 7 shows integrated trip characteristics and comparison with base condition.

Origin	Destination	Euclidian distance(km)	Base condition	
			Network distance (km)	Travel time (min)
Megenagna	Semit	5.93	7.22	24
Megenagna	Kotebe	4.3	7.2	10
Megenagna	Kasanchis	3.4	3.94	9.5

Table 6: Base condition of trips from origin to destination

Integrated service							
Origin	destination	Feeder route 1 (Taxi)		Fixed route (LRT)		Total distance	Total travel time + transfer time
		distance	Travel time	distance	Travel time		
Megenagna	Semit	5.23	6.97	2.61	1.96	7.84	13.93
Megenagna	kotebe	1.851	3.5	3.619	2.71	7.238	6.21
megenagna	kasanchis	0.9	2.2	3.2	2.46	6.4	7.16

Table 7: Trip served by integrated system

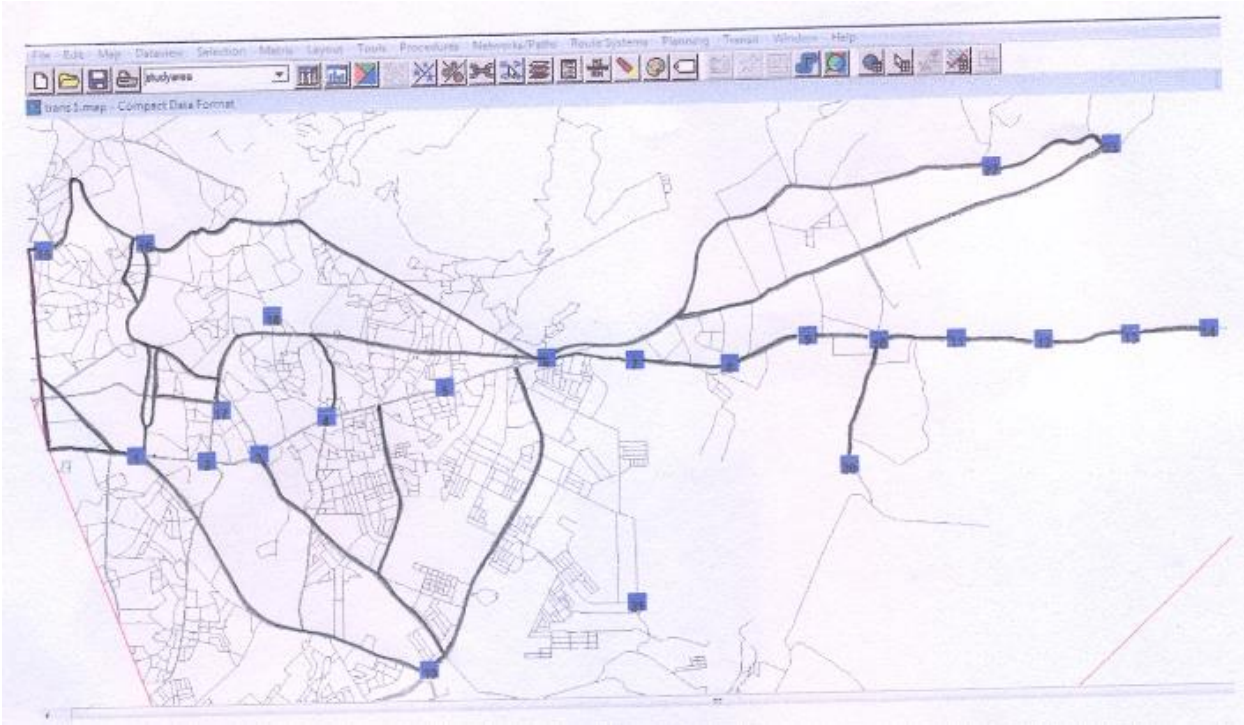


Figure 12: Trans CAD result of total network layout of trip which use the existing network

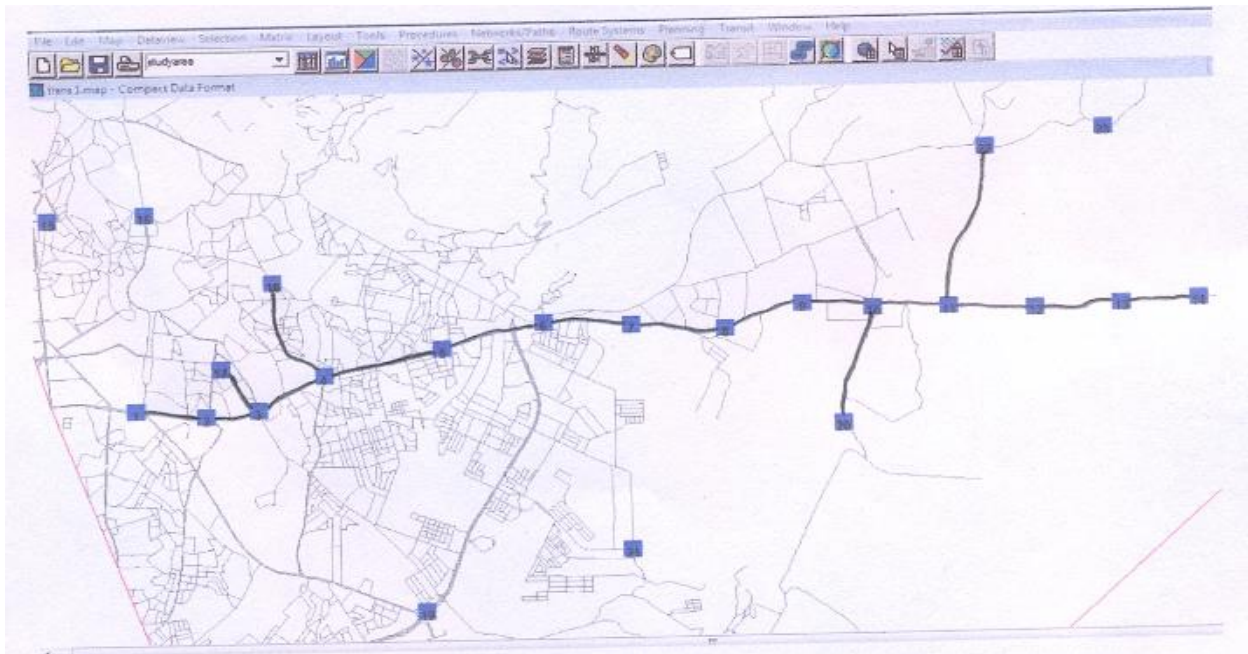


Figure 13: Trans CAD result of total network layout of trip which use the integrated trip

6.4.2 Number of demand responsive vehicle in each route

In this section it is tried to determine the number of demand responsive vehicle needed for each trip made in the study area. From each origin and destination, the number of passengers and the travel time to complete the trips was conducted through field survey. It was assumed that fixed route vehicle has infinite capacity and demand responsive vehicle has capacity of 12 passengers per vehicle.

The first step for determining the number of vehicle is to calculate the total time a vehicle needs to complete a single trip that is; a time needed to pick up a passenger at the origin plus travel time in-vehicle and a time needs to drop off a passenger at destination (column 5 in Table 8). The total time multiplied by two will gives us a time needed for a single vehicle to complete its journey. The next step is determining the number of trips a single vehicle can makes per hour (column 3 in Table 8). Finally, we can determine the number of vehicles that should serve in each route. Table 8 shows details of demand responsive vehicles.

Table 8: Number of demand responsive vehicle (taxi) in each route

Origin	Destination	No of passenger/hr	Travel time (min)	Total time a vehicle needs to cover a single trip (travel time+pick up and dropff time)	number of trip made/hr	Number of trip a single vehicle can made/hr	Number of vehicle
Meskel sq.	Bole	464	9.5	14.5	38.67	2.07	18.69
Meskel sq.	Megenagna	336	15	20	28.00	1.50	18.67
Meskel sq.	Kasanchis	72	5.5	10.5	6.00	2.86	2.10
Meskel sq.	Aratkilllo	384	7.5	12.5	32.00	2.40	13.33

Meskel sq.	Piasa	316	9	14	26.33	2.14	12.29
Megenagna	Bole	1026	16	21	85.50	1.43	59.85
Megenagna	Meskel Sq.	200	17	22	16.67	1.36	12.22
Megenagna	Piasa	660	34	39	55.00	0.77	71.50
Megenagna	Gerji	400	16	21	33.33	1.43	23.33
Megenagna	Hayahuletmazoria	200	13	18	16.67	1.67	10.00
Megenagna	Kara	186	31	36	15.50	0.83	18.60
Megenagna	Semit	220	35	40	18.33	0.75	24.44
Megenagna	CMC	120	18	23	10.00	1.30	7.67
Megenagna	Aratkillo	664	25	30	55.33	1.00	55.33
Bole	Piasa	326	28	33	27.17	0.91	29.88
Bole	Aratkillo	462	22	27	38.50	1.11	34.65
Bole	HayahuletMazoria	224	13.5	18.5	18.67	1.62	11.51
Bole	Megenagna	484	19	24	40.33	1.25	32.27
Bole	Kasanchis	228	16.5	21.5	19.00	1.40	13.62
Bole	Meskel Sq.	316	10	15	26.33	2.00	13.17
Kasanchis	Piasa	368	14	19	30.67	1.58	19.42
Kasanchis	Bole	1008	14	19	84.00	1.58	53.20
Kasanchis	Meskel Sq.	240	8.74	13.74	20.00	2.18	9.16
Kasanchis	Aratkillo	678	12	17	56.50	1.76	32.02
Kasanchis	Megenagna	498	7	12	41.50	2.50	16.60
Aratkillo	Megenagna	500	19	24	41.67	1.25	33.33

Aratkilllo	Paisa	246	6.5	11.5	20.50	2.61	7.86
Aratkilllo	Meskelsq	224	9	14	18.67	2.14	8.71
Aratkilllo	Bole	348	18	23	29.00	1.30	22.23
Aratkilllo	Kasanchis	690	16	21	57.50	1.43	40.25
Paisa	Aratkilllo	344	4.2	9.2	28.67	3.26	8.79
Paisa	Megenagna	952	26	31	79.33	0.97	81.98
Paisa	Bole	480	15	20	40.00	1.50	26.67
Paisa	Meskel sq.	360	17	22	30.00	1.36	22.00
Gerji	Bole	246	32	37	20.50	0.81	25.28
Gerji	Megenagna	300	27	32	25.00	0.94	26.67
Ayat	Megenagna	870	33	38	72.50	0.79	91.83

Table 8 indicates the number of taxis that should serve for each origin-destination trip based on the demand of passengers and travel time of taxis on the route. As we can see from the table, the number of taxis needed to satisfy the demand is greater than the current number of taxis serving in the route. Therefore, in order to satisfy demand of the passenger, the current demand responsive vehicle capacity should be greater than the capacity of the existing minibus. Increasing the number of minibuses also might be another solution but when the number of vehicles increase travel time also increase this might cause excessive delay to the vehicle and create congestion in the networks.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

The study of this paper is tried to assess the current public transport system in the city of Addis Ababa and identified the major problems that exist in the study area and the study also tried to create network integration between newly constructed LRT system and minibus, which is the existing public transport system in the city.

In order to assess the current public transport service, primary are conducted and secondary data were collected from Addis Ababa Transport Bureau and Anbesa City Transport Bus Enterprise and observational study was conducted.

The results obtained through the assessment indicated that the public transport demand is mainly served by Anbesa City bus, medium bus (Higer) and minibus taxi. As indicated in the result, the demand of the public transport and the provided service are not proportional in the city. At peak hour in almost all stations there is a long queue of passenger waiting for a taxis. From the study, it was found that shortage of service quantity, low level of safety, poor service quality, poor service accessibility, inappropriate vehicle type and size and lack of integrated network design are the major problems that exist in the city.

By taking East-West corridor of light rail transit as a case study, the paper also tried to create seamless transport service by integrating two modes of public transport services by using TransCAD software and Excel solver. The necessary input for the analysis has been conducted in the study area.

Bases on the result of the analysis it was found that 75.68% of the total trips use the existing route to travel from their origin to destination; around 10.81% of the trips use only light rail vehicles to travel from their origin to destination and the rest 13.51% of the trips use integrated trip.

For each trip we had also prepared number of demand responsive vehicle that should serve in each network. From this result we have found that the number of minibuses currently in service is not proportional to the demand of the passenger in the corridor. The proposed numbers of vehicle are much higher than the number of vehicles currently in service.

7.2 Recommendations

The study result shows that, different problems exist in the public transport service in the city. In order to avoid this problem and to fill the gap between the demand and the current transport supply, it is shown that the Addis Ababa City Road Authority launched large scale road projects similarly; the Ethiopian Railways Corporation launched the implementation of a light rail transport facility.

In order to avoid the current shortage of public transport system, it is necessary to make stagger the operating hours of different institutions like educational, civil service, financial and other institutions, because various institutions demand the provision of public transport service at about the same time.

In the context of Addis Ababa, the case study is also limited to the specific case of East-West corridor of LRT from Ayat to Meskel Square. A more complete picture of integrated service can be found if the effect and interaction of the major transportation corridors of the city, the other corridor of LRT (South–North), the ring road and the entire Addis Ababa city are taken into account.

A more complete picture of integrated service might be found if other modes of public transport system like Higer buses and Anbessa city buses were considered in the analysis.

To use TransCAD software for integration network design, we had faced different problems regarding the data. The updated road network map of Addis Ababa cannot be found easily in the concerned governmental organization. Therefore, we were forced to use outdated road network map and so we tried to edit the map by using ArcMap. Therefore,

for further research, well organized updated road network map should be provided by the Addis Ababa Transport Bureau.

From the integrated network analysis it was found that the number of trips served by integrated system is small as compared with the total number of trips made. This is due to the LRT corridor has only one route in the study area. Therefore, in order to get more integrated system the whole corridor of LRT should be analyzed.

The capacity of demand responsive vehicles is limited to 12 passengers per vehicle. Within this capacity, the number of minibuses assigned for passenger demand is much higher than the current number of taxis. Increasing the number of minibuses would create delay and congestion on the current network; therefore, it is necessary to substitute the minibus with the higher capacity demand responsive vehicle.

All the concerned institutions and stakeholders dealing with public transportation and urban development, such as: Addis Ababa City Roads Authority, Addis Ababa Transport Authority, Master Plan Office, Addis Ababa City Bus Enterprise, Federal Transport Authority, Ethiopian Railways Corporation and the like should channel their efforts towards increasing urban mobility in Addis Ababa and create a medium that would allow a smooth flow of information both at political and technical levels.

7.3 Future Research Area

More research must also be made on how the cost for the operator is affected by the introduction of an integrated public transport service. This can be an important factor to convince local authorities and operators of public transport of the benefits of an integrated service.

Appendix 1

A. shows morning peak hour demand for taxi and higer

passanger/ hr

				Taxi	Higer
From	meskek sq.	to	Bole	464	
			Megenagna	336	
			Kasanchis	72	
			4 killo	384	
			piasa	316	
no					
From	Megenagna	to	Bole	1026	960
			Stadium	200	60
			Piasa	660	480
			Mexico	400	240
			22mazoria	200	no
			Kotebe	186	1240
			Semit	220	240
			CMCayat	120	240
			4 killo	664	220
no					
From	Bole	to	Piasa	326	no
			4 killo	462	no
			22mazoria	224	no
			Megenagna	484	240
			Kasanchis	228	No
			Stadium	316	No
no					
From	Kasanchis	to	Piasa	368	No
			Bole	1008	No
			Stadium	240	No
			Megenagna	498	No
			4 killo	678	No
no					
From	aratkillo	to	Megenagna	500	No
			Paisa	246	60
			Stadium	224	No
			Bole	348	No
			Kasanchis	690	No

From	Gerji	to	Bole	246	No
			Megenagna	300	No
					No
From	Paisa	to	4 killo	344	60
			megenagna/ kas	1952	480
			Bole	480	No
			Stadium	360	No
From	Ayat	to	megenagna	870	200

B. Afternoon peak hour demand for taxi and higer

passanger/
hr

				Taxi	Higer
From	meskek sq.	to	Bole	350	No
			Megenagna	200	
			Kasanchis	120	
			4 killo	454	
			Paisa	256	
From	Megenagna	to	Bole	960	856
			Stadium	36	248
			Piasa	594	556
			Mexico	216	240
			22	192	No
			Kotebe	384	2640
			Semit	240	420
			CMC	144	240
			4 killo	720	220
From	Bole	to	Piasa	120	No
			4 killo	72	No

			22mazoria	720	No
			Megenagna	912	180
			Kasanchis	312	No
			Stadium	288	No
From	Kasanchis	to	Piasa	226	No
			Bole	880	No
			Stadium	454	No
			Megenagna	682	No
			4 killo	544	no
From	aratkillo	to	Megenagna	306	no
			Paisa	348	60
			Mexico	320	no
			Bole	248	no
			Kasanchis	300	no
From	gerji	to	Bole	320	no
			Megenagna	342	no
					no
From	piasa	to	4 killo	452	60
			megenagna/ kas	760	420
			Bole	462	no
			Stadium	334	no
From	ayat		Megenagna	554	346

c. Anbessa city bus routes

route no	starting point	end point	no of passanger
			per hr
1	Megenagna-salitemihiret- Kara		
	Megenagna	Kara	152
	Kara	Megenagna	304
	salitemihiret	Kara	72
	Kara	Salitemihiret	90
9	Paisa	Bras	84
	Bras	Paisa	75
	Kasanchis	Bras	34
	Bras	Kasanchis	56
10	Kotebe	Paisa	120
	Paisa	Kotebe	60
	shola gebeya	Paisa	74
	Paisa	shola gebeya	35
15	Megenagna	Merkato	120
	Merkato	Megenagna	120
	4 killo	Merkato	42
	merkato	4 killo	47
22	semit condominium	Legehar	154
	legehar	semit condominium	141
	cmc	Megenagna	45
	megenagna	Cmc	22
23	lamberet	Merkato	65
	merkato	Lamberet	43
	6 killo	Merkato	23
	merkato	6 killo	18
	megenagna	Legehar	76
	legehar	Megenagna	112
39	bole school	Merkato	113
	merkato	bole school	90
	4 killo	Kasanchis	78

	kasanchis	4 killo	54
40	karalo	Merkato	108
	merkato	Karalo	136
	lamberet	Merkato	6
	merkato	Lamberet	7
42	megenagna	Legehar	27
	legehar	Megenagna	42
46	gerji	4 killo	243
	4 killo	Gerji	249
	22 mazoria	4 killo	115
	4 killo	22 mazoria	80
49	chefaayat	megenagna	308
	megenagna	chefeayat	249
	cmc	megenagna	24
	megenagna	cmc	14
57	kara	legehar	86
	legehar	kara	52
	hanamariam	megenagna	62
	megenagna	hanamariam	28
61	chefaayat	legehar	145
	leghar	chefeayat	91
	cmc	megenagna	38
	megenagna	cmc	20
64	gorfaswegag	6 klllo	84
	6 killo	gorfaswegaj	33
	kasanchis	6 kilo	67
	6 killo	kasanchis	34
70	aware	ayertena	97
	ayertena	aware	118
71	gerji	balcha hospital	119
	balcha hospital	gerji	58
	22 mazoria	balcha hospital	29
	balcha hospital	22 mazoria	12
74	cmc	merkato	123
	merkato	cmc	100
	urael	merkato	45
	merkato	urael	32
78	gofacondomimum	megenagna	76

	megenagna	gofa condominium	13
	mexico	megenagna	34
	megenagna	mexico	43
79	4 killo	semit condominium	23
	semit condominium	4 killo	52
	megenagna	semitmegtetya	54
	semitmegtetya	megenagna	41
80	semen gebeya	megenagna	80
	megenagna	semen gebeya	177
	kasanchis	megenagna	96
	megenagna	kasanchis	52
83	chefaayat	6 killo	168
	6 killo	chefeayat	37
	cmc	megenagna	17
	megenagna	cmc	33
93	bole bulbula	megenagna	92
	megenagna	bole bulbula	72
	bole mikael	megenagna	24
	megenagna	bole mikael	30
96	gorosefer	megenagna	84
	megenagna	gorosefer	140
	gerji	megenagna	19
	megenagna	gerji	12
101	megenagna	aba kirosadebabay	152
	aba kirosadebabay	megenagna	104
	meri	megenagna	34
	megenagna	meri	26
102	kara	legehar	110
	legehar	kara	146
	megenagna	legehar	43
	legehar	megenagna	25
106	megenagna	goroadebabay	80
	goroadebabay	megenagna	120

8. REFERENCE

Borndorfer, R. G. (2004). *Models for line planning in public transport*. Berlin: Konrad-Zuse-Zentrum für Informationstechnik.

Carl, H. (2006). *A Framework for Evaluation and Design of an Integrated Public Transport System*. Sweden: Norrköping.

Ceder, A. (2003). *Public transport timetabling and vehicle scheduling*. Pergamon: Advanced Modelling for Transit Operations and Service.

Consultants, I. T. (2005). *Study of urban public transport conditions in Addis Ababa Ethiopia*.

Dadson, J. M. (2011). *The Principles of Public Transport Network Planning: A review of the emerging literature with select examples*. Brisbane: Griffith University.

Desilet, A. &. (1992). *a computer-assisted tool for the synchronization synchronization*. In Proceedings of the Fifth International Workshop on Computer-Aided Scheduling of Public Transport.

Domschke, W. (1989). *Schedule synchronization for public transit networks*. OR Spektrum.

Fleurent, C. L. (2004). *Transit timetable synchronization: Evaluation and optimization*. Presented at the 9th International Conference on.

Hagani, A. &. (2002). *Heuristic approaches for solving large-scale bus transit vehicle scheduling problem with route time constraints* (Vol. part A). Transportation Research.

Hickman, M. &. (2001). *An Investigation of Integrated Transit Service*. (Vol. USA). Research Report SWUTC/01/472840-00023-1.

Ibraim, M. (2003). *improvements and integration of a public transport system : the case study of singapore* (Vol. 20). singapor: Elsevier Science Ltd.

Kirby, R. B. (1974). *Para-Transit:Neglected Options for Urban Mobility*. Washington D.C: The Urban Institute.

Liaw, C. W. (1996). *A decision support system for the bimodal* (Vol. part A). IEEE Transactions on Systems, Man, and Cybernetics.

Luk, J. &. (2003). *Integrated public transport in Singapore and Hong Kong* (Vol. 12). Road & Transport Research.

Meron. (2007). *Public transportation system and its impact on urban mobility:The case of Addis Ababa*. Addis ababa.

Mohammad, V. &. (2012). *Integration in Urban Public Transport*.

Transprt Reseach Program (2003). *Integration and regulatory structures in public transport*. University of Oxford: Transport studies unit.

Nielsen, G. (2007). *NETWORK DESIGN FOR PUBLIC TRANSPORT SUCCESS – THEORY*.

Simpson, B. J. (1994). *Urban Public Transport Today*. London: E & FN Spon.

Wilson, N. &. (1999). *Performance models of flexibly routed transportation*. Flexibel kollektivtrafik i Gøteborg.

Wong, S. &. (2003). *The estimation of origin-destination matrices in transit networks*. Pergamon: W. Lam & M. Bell.