DOCTORAL DISSERTATION

博 士 論 文

FEEDER NETWORK DESIGN TO ACCESS AN EXISTING BUS RAPID TRANSIT SYSTEM IN LAHORE

ラホール市の既設 BRT 路線にアクセスする支線バスネットワークの設計に関する研究

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ABSTRACT

Now-a-days many developing countries are suffering from high motorization trend that has produced several unwanted by products. Though private vehicles provide high level of access and freedom but have enormous associated risks in the form traffic congestion and accidents, noise and air pollution and high energy consumption. Admitting these facts, many developing countries have initiated efficient mass transit systems to relieve these side effects. These systems provide a comfortable, safer and efficient services and so can be fairly preferred over private vehicles. Also the target of these systems is same as to cut down the private vehicle usage by attracting commuters from diverse social income classes other than low ones. However most of these systems are planned and designed independently, leading to the difficulties in accessing and egressing. Accessibility of these systems, which is one of the basic components of performance measure used for transit (Wardman 2004), is still crucial in most of the developing countries. Lack of any regular feeder services creates gap between ones' origin and mass transits station that cause dissatisfaction to commuters and they lose patronage towards these systems. Currently paratransit is emerging as dominating feeder mode in several developing countries and connecting commuters from residence to public transport systems. However these paratransit have certain service areas and potential passengers. Also most of these are informal, not well organized and unsatisfactory and their movement is restricted to certain parts of the cities. Therefore a detailed evaluation is essential, also from commuters' viewpoint, before implementing them as feeder.

Unlike paratransit, a regular feeder bus, a form of public transport, can provide safer, comfortable and reliable service and will be free from the enormous risks as associated with paratransit. However a regular feeder bus requires a careful and vigilant planning and design. The precise selection of potential demand locations and appropriate approach to generate optimized feeder routes can result in the development of successful feeder bus operation. Optimized feeder routes can reduce the overall journey time of commuters while travelling in a comfortable mode. The purpose of the feeder route is to connect all the destinations for which demand generates from the mass transit station. All the previously proposed models for feeder routes generation are applied through conventional engineering approach; in which routes are generated separately for each station by assigning certain route generation nodes to a station. However a route generation node is a part of network and might be connected by some other stations too, its distance or travel time might be improved by inserting it in any other route for any other station. This issue remains unknown in typical approaches and some improvements are required to consider all or multiple consecutive stations simultaneously. Therefore this research intends to improve the conventional application method of route generation which can help in decision making by providing a set of solutions. The improvement in the current approach also aims to reduce the overall route network length to lower the operators' cost.

For this research, Lahore; the second largest city of Pakistan is selected as the study area. Lahore has a mass transit system in the form of Bus Rapid Transit System (BRT). Currently no regular feeder service is provided with the system and only existing modes are being used for feeder purpose. The existing modes are comprised of conventional public transport (public buses) and informal paratransit (auto rickshaw and motorcycle rickshaw). The role of auto rickshaws as feeder is almost equal to none being costly and fewer in number, whereas motorcycle rickshaws have made deeper inroads and are being used as feeder most frequently. In order to understand the current travel pattern and characteristics, two kinds of field interview surveys were conducted during Feb-March, 2015, with the help of university under graduate students. The first type of survey was conducted at few BRT stations comprising of 311 samples while the other was conducted nearby offices, workplaces and activity centres which made up 296 samples. The collected questionnaire data was analysed step by step and finally structural equation modelling techniques were applied. The results of the study revealed that currently major BRT users belong to low income class and those who own no vehicle. Among these users, work commuters are significant of all, which is also due to the location of BRT corridor that provides direct access to many workplaces. The commuters who own private vehicle and belong to other than low income class are more prone to use their own vehicle than BRT, even if they can make their egress trips by walk only. As far as the feeder mode is concerned, majority of BRT users are those who can make their access or/and egress trip by walk only. However the share of walk for the egress trip is dominant due to the proximity of workplace locations from BRT stations. After walk paratransit has greater share than public transport. For public transport, results of spatial analysis reveal that majority of city's population is living far from the nearest bus stop and so cannot avail public bus as feeder. Whereas for paratransit commuters perception show that commuters are most dissatisfied by the vehicle quality as it offers bumpy, uneven and risky travel and also the service reliability. Further results show that in order to improve the BRT accessibility, all these dissatisfied factors must be dealt. Replacement of paratransit with feeder bus is a desirable option, also commuters show strong willingness to pay for the regular feeder bus.

The study further suggests few preferred towns to initiate feeder service based on residential landuse type, owing higher density and uniformly populated. It also introduced an improved approach for optimized feeder routes generation. In the proposed improved approach feeder routes are generated, *simultaneously* for multiple adjacent (or for all) stations. The proposed approach yielded better optimization with lesser computational time and effort. The altogether insertion of all demand points for all the selected stations not only minimizes the average route length but total sum of all route lengths as well. This mechanism is found to be beneficial in achieving better trade-off between users and operators interests, when compared with the conventional approach. Therefore it is recommended to apply proposed approach to gain better optimization results. Based on the study findings, other developing countries must consider local differences and service area and passengers for various types of paratransit. In the end recommendations have been made for future work by proposing constrained multi objective optimization and incorporating other social income classes for evaluating paratransit.

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Chapter 1

INTRODUCTION

1.1 RESEARCH BACKGROUND

The rapid increase in urban population and travel demand has resulted severe traffic congestion and several unwanted by products in developing countries. In most of the developing countries; Mobility is mainly dependent on automobile. The trend of automobile ownership and usage has changed the shape of many metropolitan areas and way of travel (Susilo and Kitamura, 2008). The main reasons of increase in automobile ownership and usage are low ownership and usage cost, status symbol, government policies on vehicle ownership, and inefficiency and under development of public transportation systems. The trend of travelling publically is more or less limited to low income group who are transit captives. The rate of vehicle ownership growth is more in some cities of developing countries compared to developed countries as shown in Figure 1.1. Admitting these facts many metropolitans of developing countries have implemented efficient Mass Rapid Transit systems in the past decades such as Bus Rapid Transit (BRT) in Jakarta, Seoul, and Curitiba as well as rail-based systems, Light Rail Transit/ Heavy Rail Transit / Subway in Bangkok, Delhi, and Manila.

Generally, most of mass transits implemented are located along the high-density and the long been developed urban areas with anticipation to reduce number of car usages and obtain adequate ridership from those areas. Unfortunately, in many developing societies, the ultimate goal of attracting commuters from other than low income group, is still far to achieve. One of the main hindrances in achieving target; is the critical issues associated with the accessibility of these efficient systems. The difficulties in accessing mass transits and public transports are mostly caused by inefficient land use plans, low service coverage, and inadequate feeder systems. Even though mass transit systems offer high speed service as private car does or sometimes even faster, car users still have not transferred to ride mass transits. This is because automobile

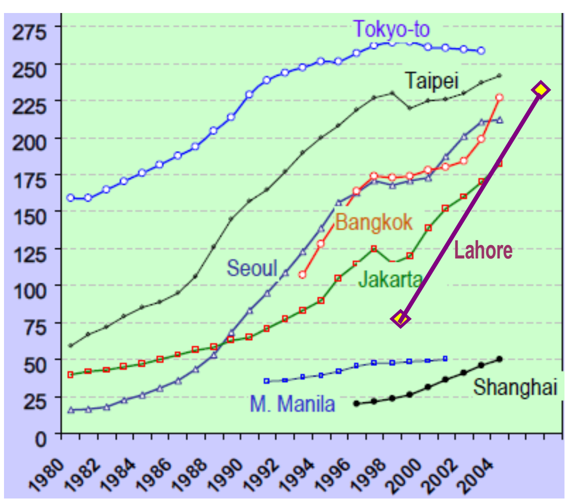


Figure 1.1 Pattern of Vehicle growth

can satisfy commuters' needs of door-to-door service that present mass transit systems cannot offer. Since, access is the starting point of public transport trips, if choice commuters have to suffer at the start of the travel, they will definitely prefer their private vehicle. Therefore, the effective feeder system along the mass transit corridors is an important key and urgently required in order to fade away the weakness of mass transit systems. The feeder system should provide more convenience not only for the transit captives but for the choice riders as well. Also, public transit systems should not be designed and implemented in isolation [NUTP, 2005], as system designed in isolation will not be able to shift the choice commuters to public transit, and this is what developing countries are suffering from. A public transport system does not end at the entry or exit door of the station, but rather encompasses the entire potential user's catchments area [Jumsan et.al, 2005]. If commuters cannot reach a station comfortably and safely, then they will cease to be customers.

Previously many researchers has strongly recommended the use of paratransit as a feeder mode (Satiennam et al., 2006, Akkarapol et al., 2009, Shimazaki et al, 1996 and Okada et al. 2003). Several types of modification and improvement polices are also proposed to support paratransit as feeder. But still most of the paratransit services are illegal, unregistered and have enormous risks. Although the highly mobile and flexible nature of paratransit allow them to penetrate into the residential streets, offering high access. However these have specific service areas and potential passengers, mostly low lying areas and low income class. Not only this, level of service of current paratransit is not sufficient enough that can bring commuters out of their comfort zone i.e. their private vehicles/ cars. This is one of the important issues due to which these efficient mass transit systems have not yet achieved their target and still transit captives are the only main users. Therefore it is vital to careful evaluate each paratransit type and other modes before implementing them as a regular feeder service.

Evaluation methods for transportation system can affect the perceived value of public transit. Different evaluation methods give very different conclusions concerning the value of a particular service or improvement. The selection of evaluation method is not simply a matter of opinion or preference. Comprehensive evaluation is essential for producing accurate results [Litman, 2011]. Evaluating transit service quality from various perspectives, includes factors such as Availability, Frequency, Travel speed, Reliability, Integration, Price structure and payment options, User comfort and security, Accessibility, Universal design, Affordability, Information, Aesthetics and Amenity. For example; Kittelson & Assoc. utilized Transit Level of Service Indicator to evaluate the transit system based on coverage, frequency, span, population and jobs in the city [Kittleson and Assoc., 203 a,b].

1.2 PROBLEM STATEMENT

In many developing countries, the accessibility of the core system (mass transit) is still crucial. Since neither regular feeder services are designed nor are existing available modes evaluated well to be used as efficient feeders. Therefore in the unprivileged scenarios either those who can make feeder phase by walk (live or/and work nearby) or those who are willing to use current modes as feeders are the only users. Among these current feeders; paratransit has made much deeper inroads. Considering their flexibility and mobility their potential as a feeder mode is supported many times before in literature. However one should not forget the grounds and target of initiating these efficient mass transit systems, while supporting paratransit as feeders. Moreover; Paratransit services have certain potential passengers from specific social income group; also in many developing countries the operation of paratransit is limited to certain areas. Whereas the inefficiency and insufficiency of other conventional public transport system in terms of quality and coverage, is one of the main factors behind introducing quality mass transit systems. Previously many improvement policies for paratransit are proposed, however none of them can make these a quality vehicle, particularly for choice riders. Paratransit can definitely serve certain localities, but their role as feeder mode is overestimated.

A luxuries, comfortable, safer, and efficient and environment friendly mass transit system is introduced to make rich travel publically and to cut down the usage of private vehicle; and then existing modes (which were poor enough) are supported as feeders, makes no sense, and so will never succeed in attracting choice riders. The existing modes must be improved and enhanced to raise their level of service, but improving them to the level that will change their potential passengers altogether is not realistic. A quality mass transit system must be supplemented by quality access, and that's one of the ways for achieving target. However a regular feeder bus requires a vigilant planning to be effective. A trip using feeder bus, and then main transit system includes detour factor from the destination, therefore feeder routes require to be as much optimized as can be.

In general the research questions are as following;

1. *Are the existing services efficient and sufficient enough to provide quality access for a quality mass transit system; in terms of coverage and service quality attributes?*

   The concept of using existing modes as feeder comes from the thought; 'utilizing the existing resources' and so to keep the overall network's cost low. However existing services including conventional public buses and paratransit must be evaluated on each possible ground. The quality and level of service of feeders must be in comparison with the system whom they are feeding to.

2. *What are the underlying factors for the current feeder modes, users are most concerned about?*

   Currently when there is no specific regular feeder service is available, commuters have no choice other than using existing modes. Knowing and evaluating commuters' perception regarding these feeders, can play a significant role in identifying the most crucial aspects of these modes.

3. *Is a regular feeder bus service a feasible alternate solution, other than paratransit?*
   A regular feeder bus other than the existing conventional modes is a desirable option that improves the quality of travel during feeder phase. However the operation of feeder bus is not straight forward and it requires detailed feasibility. Considering current scenario and commuters' perception for the existing modes and their willingness towards a regular feeder bus can reveal the potential for such service.

4. *Which technique, other than the conventional one, can be used to generate optimized feeder routes?*
   Feeder routes are critical to design since feeder route length directly affects the passengers' travel time which is more important in case of feeder, as a feeder trip includes transfer activity (Bhat et.al.2013). Feeder routes design problem i.e. serving all the demand points in an efficient manner yielding lesser travel time for passengers, can be solved as an optimization problem. The choice of a particular technique for optimization can generate diverse results and so must be well evaluated considering problem's building method suitability.

5. *How to determine an optimized approach for feeder routes generation, considering multiple stations simultaneously?*
   In the literature review various techniques have been applied for solving feeder network design problem; however all of these are used to solve the problem per station that resulted into repetitive modelling exercise. Although few researchers have used Multi Depot Vehicle Routing Problem (MDVRP) where multi depot is for multi stations, but even for the case, the assignment of route generating points is done prior to the route generation and is on the decision makers' side. This approach includes human preconceptions and biases in assignment of certain points for a particular station. Therefore these current approaches do need improvements to generate better optimized solution.

1.3 RESEARCH GOAL AND OBJECTIVES

The main goal of the research is to propose a quality feeder service in the form of feeder bus/ shuttle, based on the commuters' perception over current feeders, and development of an optimized approach for the generation of feeder routes, by selecting Lahore city as the study area.

To attain this goal following are the objectives:

1. To examine the current feeder pattern; what are and how much?; Assessment of feeder modal share (Chapter 4)

2. To explore and evaluate the potential of current modes as BRT feeders; Based on Users' perception (Chapter 5)

3. To identify the need of a regular feeder service by Bus/Shuttle and validation of its utmost significance (Chapter 6)

4. Feeder Network Design; A Land Use based Approach towards Selecting Potential Demand areas for Feeder (Chapter 7)

5. Feeder Network Design; Development of Optimized Feeder Routes by applying GA (Chapter 8)

   a. Through conventional approach, station wise,

   b. Through simultaneous determination of influence zones for multiple stations, simultaneously

1.4 SCOPE AND LIMITATIONS OF STUDY

The outcome of the research will help to design feeder network in a more optimized way. Following are the main application of the study;

- ✓ The study explains the malfunctioning of current public transport and paratransit in terms of area coverage and service quality.
- ✓ The study proves the incompetency of current available modes to be used as quality feeders
- ✓ The study suggests a regular feeder service in the form of shuttle, considering users' perception
- ✓ It further suggests the most influencing landuse factors for initiating a regular feeder service in a certain area
- ✓ For the proposed feeder bus, an improved approach of generating optimized feeder routes is suggested

However study has following limitations;

- ✓ Limited sample size of field surveys, may generate under/overestimated results.
- ✓ The target of widespread ridership for a mass transit system, may not be achieved by a stand-alone policy of proposing a regular feeder bus owing optimized routes; it does need effective role of several other strategies as well
- ✓ The operation of feeder bus is not as straightforward; appropriate subsidy may be needed for effective operation.

- ✓ Other developing countries may have many types of paratransit services for certain potential groups; therefore results from this study cannot be applied as it is. The effect of local scenarios should be taken into account.

1.5 OUTLINE OF DISSERTATION

There are a total of 9 chapters in this dissertation. This chapter starts to introduce the background that why a regular feeder bus service other than the existing modes is more needed. The remaining chapters are arranged as follows:

Chapter 2: This chapter describes the research background and motivation. It includes the existing researches about the feeder network design. It also includes the details of various feeder systems adopted around the world.

Chapter 3: This chapter describes the various steps of research methodology. These steps include selection of case study area, data collection methods, and background of data analysis methodologies. It provides an overview of the study area characteristics from transportation point of view.

Chapter 4: This chapter elaborates the very first finding of the field surveys i.e. feeders' modal share. It shows the share of each mode being used as feeder.

Chapter 5: This chapter evaluates the existing feeders in two aspects; spatially and qualitatively based on users' perception. The first part of the chapter provides a spatial analysis, done for public transport only. Whereas the second part evaluates both (public transport and paratransit) based on the field survey results from service quality view point, considering commuters' perception.

Chapter 6: This chapter shows the impact of current feeders over accessibility of the main system (BRT). Further it signifies the potential of regular feeder bus over the existing modes. Technique of structural equation modelling is applied for the said purpose.

Chapter 7: This chapter finds the most contributing landuse factors for feeder trip generation. Based on these, few areas are preferred and considered to provide potential ridership for feeder bus.

Chapter 8: In this chapter, feeder routes are generated as a result of optimization problem. Problem is solved by applying Genetic Algorithm (GA). Firstly conventional approach is used, secondly few improvements are introduces to modify the conventional approach which yielded better optimum solution.

Chapter 9: This chapter summarizes the main findings and policy implications of this study. At the end, recommendations are made for future research.

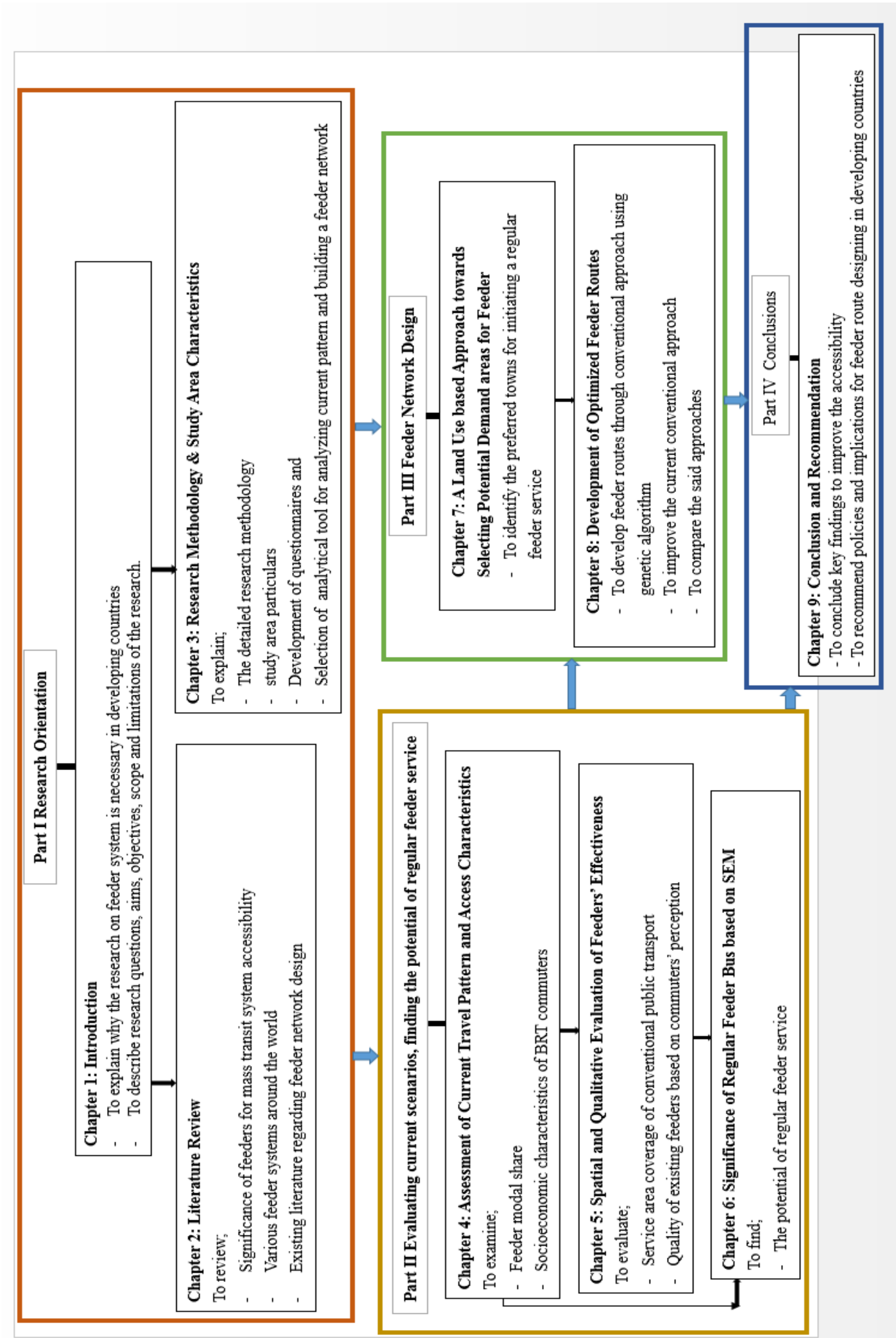


Figure 1.2 Interrelated research scheme

Chapter 2

LITERATURE REVIEW

(Existing Researches on Mass Transit Systems' Accessibility and Feeder Network Design)

For all kind of mass transit systems, accessibility is very important because the ease to access the system greatly influence one's choice towards using the system. Therefore accessibility can in turn substantially increase or decrease the transit systems' ridership. Accessibility is a combined result of the transportation system and land use patterns. The transportation dimension of the measure is typically referred to as the impedance and may be measured as travel time or distance. The land use dimension of accessibility may be referred to as the attractiveness, opportunity, or activity.

To increase ridership, access from residential areas to mass transit station should be improved in terms of physical environments and sense of security (Supaporn. et.al. 2013). Conveniences of accesses also encourage car users to be mass transit users and inspire non-regular mass transit users to be regular mass transit users (Givoni et. al. 2007 and Brons et. al 2009). Similarly, Selmer C. and Hale C. (2010) explain that quality of passenger access to stations and egress to destinations represents effectiveness of mass transit. In addition, accesses to mass transit stations influence commuters to use or not to use the systems. This will also affect ridership and income of the system. Therefore, agencies that provide mass transit services should pay attention to accessibility.

Generally Auto and Non-Auto access are the two main categories to access a mass transit system; each has its own merits and demerits as shown in Table 2.1.

2.1 MASS TRANSIT SYSTEMS AROUND THE WORLD

Mass transit system often referred as public transit systems is a passenger transportation service, usually local in scope, which is available to any person who pays a prescribed fare. It usually operates on specific fixed tracks or with separated and exclusive use of potential common track, according to established schedules along designated routes or lines with specific stops, although Bus Rapid Transit and trams sometimes operate in mixed traffic. It is designed to move large numbers of people at one time. Examples include Bus Rapid Transit, heavy rail transit, and light rail transit. Today, various kinds of mass transit system exist that delineate in terms of cost, capacity, and technology, and some other features might include distance between stops, extent of right-of-way, operational regimes, and guidance systems. This section provides an overview of various kinds of mass transit systems around the world.

Table 2-1 Various Access Modes for mass transit systems

Auto access	
Park and ride, kiss and ride	Access by cars is the most costly access mode for transit agencies. Land needed for parking spaces is expensive (Selmer C. et al. 2010). Providing park-and-ride also wastes large land area, generates more traffic congestions at the area around the stations. Affects environments around the stations in terms of air and noise pollutions from cars (Supaporn. et.al. 2013).
Feeder bus	A desirable option for passengers that live further than walking distance to transit stations, especially for those who do not have private vehicles or cannot afford cost of parking at transit stations. Generate less traffic congestion and emissions. However, providing feeder bus service is costly when it has to time-competitive with cars, especially in low-density areas where number of passengers is low (TCRP 2009).
Paratransit	According to paratransit's function, many researchers recommended an integration of paratransit as a feeder for public transit systems to enhance performance of urban transportation (Satiennam et. al. 2006, Akkarapol et.al. 2009, Shimazaki et. al. 1996,and Okada H et.al. 2003). Flexible and easy connectivity and utilization of existing resources. Existing services are Informal, not well organized and unsatisfactory, therefore commuters' perception is important in evaluating the possibility of paratransit as feeder (Akkarapol et.al. 2009).
Non-Auto access	

Improving non-motorized transit access i.e. bicycling and walking to mass transportation is one of the most cost-effective ways to improve air quality and manage traffic congestion (FHWA), 1992).	
Walking	Limited to those who live 400-800m from the station (5 to 10 minutes' walk). Urban design, pedestrian facilities, crime and safety perceptions, and individual characteristics such as age and gender affect walking decision (Supaporn. et.al. 2013). Distance of walking distance and selection of transportation mode are affected by walking environment (O'Sullivan et. al. 1996).
Cycling	Limited to those who live within approximately 3 kms from the station. Improvement cycling access will increase number of passengers at low access-service costs for transit providers (Supaporn. et.al. 2013). However, wide quality of bicycle facilities, topography, weather, and bicycle culture can greatly affect the cycling usage (TCRP 2009).

2.1.1 **Heavy Rail Transit**

A heavy rail transit system is "a transit system using trains of high-performance, electrically powered rail cars operating in exclusive rights-of-way, usually without grade crossings, with high platform stations" (TCRP, 1998).

2.1.2 **Light Rail Transit**

A light rail transit (LRT) system is a metropolitan electric railway system characterized by its ability to operate single cars or short trains along exclusive rights-of-way at ground level, aerial structures, in subways, or occasionally in streets, and to board and discharge passengers at track or car floor level. LRT systems include tramways, though a major difference is that trams often operate without an exclusive right-of-way, in mixed traffic (TCRP, 1998).

2.1.3 **Metro**

Metro is the most common international term for subway, heavy rail transit, though it is also commonly applied to elevated heavy rail systems (TCRP, 1998). They are the most expensive form of mass transit systems, per square kilometer, but have the highest theoretical capacity.

2.1.4 Commuter Rail System

Commuter rail or suburban rail is the portion of passenger railroad operations that carries passengers within urban areas, or between urban areas and their suburbs, but differs from Metros and LRT in that the passenger cars generally are heavier, the average trip lengths are usually longer, and the operations are carried out over tracks that are part of the railroad system in the area (TCRP, 1998).

2.1.5 Bus Rapid Transit

Many cities have developed variations on the theme of better bus services and the concept resides in a collection of best practices rather than a strict definition. Bus Rapid Transit is a form of customer-orientated transit combining stations, vehicles, planning, and intelligent transport systems elements into an integrated system with a unique identity. Bus Rapid Transit typically involves busway corridors on segregated lanes – either at-grade or grade separated – and modernized bus technology. However, apart from segregated busways, BRT systems also commonly include:

- ⇨ *Rapid boarding and alighting*
- ⇨ *Efficient fare collection*
- ⇨ *Comfortable shelters and stations*
- ⇨ *Clean bus technologies*
- ⇨ *Modal integration*
- ⇨ *Sophisticated marketing identity*
- ⇨ *Excellence in customer service* (TCRP, 1998).

Bus Rapid Transit is more than simply operation over exclusive bus lanes or busways. According to a recent study of at-grade busways (Shen et al.,1998), only half of the cities that have busways have developed them as part of a systematic and comprehensive package of measures as part of the city mass transit network that we would identify as a BRT system.

Bus Rapid Transit systems always include some form of exclusive right-of-way for buses. Elevated busways or tunnels may be needed for traversing some city centers, but in many developing cities funds will not be available for extensive grade separation.

a. Bus lane (or priority bus lane)

A bus lane is a highway or street reserved primarily for buses, either all day or during specified periods. It may be used by other traffic under certain circumstances, such as while making a turn, or by taxis, bicycles, or high occupancy vehicles.

Bus lanes, widely used in Europe even in small cities, are increasingly applied in developing cities such as Bangkok, where counter-flow buses can move rapidly through peak period congestion.

b. Busway

A busway is a special roadway designed for exclusive use by buses. It may be constructed at, above, or below grade and may be located in separate rights-of-way or within highway corridors. Some form of busway system is a feature of many Bus Rapid Transit systems.

2.2 INTRODUCTION OF BUS RAPID TRANSIT (BRT) SYSTEM IN DEVELOPING COUNTRIES

Over the past two decades, bus rapid transit (BRT) has emerged as a major alternative to a rail versus bus debate. To date, more than 150 cities have implemented some form of BRT system worldwide, carrying around 28 million passengers each weekday. At present, BRT systems worldwide comprised 280 corridors, 4,300km of routes, 6,700 stations and 30,000 buses (BRTDATA.ORG). BRT systems are currently being added at a geometric rate, gaining particular favor in the developing world, following on the heels of widely publicized BRT successes in Curitiba, Bogota, Mexico City, Istanbul, Ahmedabad and Guangzhou (Cervero 2013). These developing cities show that high-performance BRT systems that yield appreciable mobility and environmental benefits can be built at an affordable price.

The greatest success of BRTS in developing countries has occurred due to the demand of a high quality transit system without having to pay the high price of heavy rail, a lifelong dream for many developing countries unable to afford large scale infrastructure development. For these urban centers, BRT has become, in roughly 10 years, the alternative choice for mass, yet affordable and quick-to-implement, transit (Carlos Campo, 2010). It portrays a different picture of the role that buses can play in public transportation, an echelon above what regular bus service offers, entering a realm traditionally reserved for rail-based transit

Considering its advantages, to name a few cities Jakarta, Bangkok, Hanoi and Manila currently have started, planned and are considering operating BRT systems. However, a proper BRT development in these cities specifically involves many regional issues that mainly contribute to the success of BRT implementation. The most successful BRT operating cities have been developed with a well-designed city plan integrating land use strategy with public transit and road networks (Satiennam et. al. 2006). Since most Asian developing city structures have been developed under solely a road transport development city plan and weakness of land use control that gives rise to various problems of urban sprawl, traffic congestion, and air pollution, it will be rather difficult to have desired outcome from BRT system under these circumstances.

2.2.1 **Supporting Strategies for BRT System Development**

This section provides the essential conditions identified by the researchers for successful implementation of BRTS, particularly in developing countries. Developing countries own unique characteristics in terms of not only transportation and land use planning, but people perception towards using the built system also varies significantly than that of developed ones. Therefore the potential strategies should account this limitation too. Satiennam (2006) identified the strategies that will make the BRTS successful in developing countries too, if adopted, as following:

a. *Providing good organizing feeder and parking facilities*
b. *Decreasing number of local buses parallel/adjacent to BRT corridor*
c. *Introduction of an advanced signal priority system*
d. *Promoting BRT system to the public*

a. Providing good organizing feeder and parking facilities

Provision of feeder service and parking facilities are the ways to make the system usable by those who live far from the system and access it by using other modes. A well-designed BRT with feeder integration would yield significant impact in terms of getting people out of their cars and onto public transit. Feeder connections would not only increase BRT capacity, but also improve the accessibility of communities around BRT stations. Integration with other modes, motorized and non-motorized, can greatly increase BRT system performance and help reduce direct costs, since these modes can act as feeders into the system.

Many researcher recommend existing paratransit to be used as feeder service instead of introducing any other. Utilizing the existing paratransit as feeder will offer easy connectivity and also cost saving. Akkarapol (2009) revealed that paratransit, both flexible for-hire and fixed route types, show their capability to be implemented as a feeder system for mass transits and other public transports. Further, this study showed that satisfaction of mass transit connectivity has the largest positive influence over paratransit service satisfaction. This means that increase of mass transit access satisfaction will stimulate the willingness to use of mass transits and paratransit access mode.

However current paratransit services are quite irregular, informal and unorganized, and require specific improvement strategies before implementing as feeders.

At BRT stations small size parking facilities should also be properly provided, for those who access by private vehicles. In addition, long-term parking lots would be provided for small vehicles, e.g., motorcycles and bicycles. The temporary parking area would be provided for temporary parking vehicles, e.g. taxi, to pick up/drop off the BRT passengers. At the end of the BRT corridor/high demand service stations, Park & Ride (P&R) facilities would be provided for private car users to park their cars and transfer to BRT system for access to the CBD.

b. Decreasing number of local buses parallel/adjacent to BRT corridor

In urban networks of Asian developing cities, their roads are mostly congested, especially during peak hours. In establishing a cost-effective busway for the BRT, one lane of existing road being planned for BRT corridor would generally be dedicated for an exclusive bus lane. As a result, the decrease of existing road capacity would cause more congestion along/adjacent to the BRT corridor. Moreover, the operation events of existing local bus routes, such as stopping at the bus stop, would cause more interruption to the flow of mixed traffic. However, it is impractical to remove all existing local bus routes along the BRT corridor, as the BRT service would most-likely have a "skip stop" type of design to help make the BRT travel time more competitive with auto travel. As such, the BRT bus-stop spacing would be too sparse to serve the dual purposes of BRT service and local bus service. Therefore any existing local bus routes along/adjacent to the BRT corridor would remain unchanged without functioning as a BRT competitor. However, to attract more BRT riders and to improve the traffic condition along the BRT corridor, the frequency of existing local bus services should be decreased (Satiennam et. al. 2006).

c. Introduction of an advanced signal priority system

An introduction of advanced signal priority system to the BRT operation is an approach to enhance the performance and reliability of a BRT system and to reduce the impacts of BRT operation on other traffic. A good signal control design with an advance bus detection system could give priority to the bus approaching the intersection without delay. It could also minimize the increased delay of other traffic in all approaches due to bus priority operation (Satiennam et. al. 2006).

d. Promoting BRT system to the public

A marketing strategy would be conducted to the public using various types of advertising distribution to introduce the concepts, advantages among other modes, and contributions of BRT system. Brochures, websites, advertisements, etc. can be published and distributed to the public, with an attractive logo and theme specially designed to represent the uniqueness of the BRT system appealing to travelers. One effective media to introduce the comprehensive concepts, features, and advantages of BRT system to the public is video clip generated by the simulation program. Once operated, the BRT system still requires continuous updating and repackaging of market strategies to ensure its continued consumption (Satiennam et. al. 2006).

2.3 WORLDWIDE BRTS NETWORKS AND FEEDERS

BRT networks often follow the urban form. They also reflect service philosophies. Early Latin America BRT cities, like Curitiba and Bogota, have distinct radial city forms and accordingly radial BRT systems. Most trips are distributed along high-density corridors. In contrast, Chinese cities tend to have high, fairly uniformly distributed urban densities (Yang et al., 2012). Their spread-out, planar urban form calls for more flexible, multi-directional systems, such as in Guangzhou. Rather than radial or hub-and-spoke systems with transfer points, Chinese cities tend to have branching networks and flexible route designs that minimize transfers.

Ideally, a BRT network mimics the spatial coverage and connectivity of other regional transportation facilities, notably regional freeway and motorway networks. If bus based transit systems are to be time-competitive with the private automobile, it is imperative that they deliver the same degree of regional access (Cervero 2013). TransJakarta's proposed network in Indonesia at build out aims to do just that, stretching in all direction across the city of 14-million inhabitant's sprawling landscape. BRT network designs also reflect cities' public transport histories and broader policy agendas. In Seoul BRT was introduced as part of a radical service reform. There, BRT functions as high-capacity trunk lines, and most other routes have been reconfigured to serve as feeders, to cater to non- BRT markets, or provide nice-market services like downtown circulators or cross-town express lines (Cervero and Kang, 2011).

In low-income settings, such as Southeast Asia, BRT has been introduced partly to help rationalize and formalize transit services, with informal or quasi-legal micro- and minibuses, either eliminated or upgraded/redesigned, to play a complementary role, such as BRT-feeders. Long-standing private operators and other incumbents have sometimes been removed as a necessary way to achieve economies of scale and financial sustainability, with varying degrees of success (Cervero and Golob, 2011). Highly atomize quasi-informal paratransit feeder services continue to characterize BRT station areas in cities like Jakarta, Bangkok, Delhi and Lagos.

Generally the three main types of BRT systems are: (1) trunk-only, also called closed systems; (2) trunk-feeder; and (3) direct-service, also called open systems. Among exclusive-lane systems, around a dozen operate as trunk-only systems, with BRT buses operating only along dedicated running-ways. Among the largest BRT exclusive-lane systems, trunk-only, closed systems are found in Jakarta, Ahmedabad, Beijing, Xiamen and Istanbul. Of course, all of these systems have regular buses and sometimes minibuses that feed into stations however they are not part of the BRT system and operated instead by different (mostly private) operators. In Latin America, trunk-feeder systems are common, featuring BRT buses that operate mainly on the trunk line, but occasionally leaving the busway and functioning as a neighborhood distributor at one end of the route. More commonly, however, smaller buses featuring a different color scheme and operated by the BRT Company of feeder services. Trunk-feeder BRT operations are today found in Bogota, Curitiba, Mexico City, Leon, Lima and Quito. Bogota's green-color midi-buses, for example, provide free connections between mostly informal housing settlements and TransMilenio's terminal stations. European BRT systems apply a mix of service designs. In Nantes, Stockholm, Catellon and Jonkoping (Sweden), BRT operates as trunk-feeder services. In cities like Lorient, Madrid and Gothenburg, buses provide direct "open" services. Direct, open services characterize BRT services in many Chinese cities. With open systems, buses enter and leave the running ways, usually at both ends of a route. This allows the integration of line-haul and feeder (i.e., collection/distribution) services. Guangzhou's open system involves multiple bus routes that converge on a single dedicated BRT corridor, each serving different origin-destination patterns.

2.4 FEEDER NETWORK DESIGN

Feeder systems play an important role for any kind of mass transit system. They connect the system with the areas that are somewhere far from the main system and originating high demand. The need of accessibility for masses to any mass transit system can be fairly achieved by introducing the dedicated feeder service.

As per the literature review feeders are mainly addressed based on the spatial accessibility, from the point of view of selecting a given number of stops for a Fixed Route Transit (FRT) such as bus (Murray, 2003; Rodriguez and Targa, 2004) and rail (Workman and Brod, 1997). However, similar studies for flexible form of transit such as Demand Responsive Transit (DRT), call-n-ride and dial-a-ride are yet to be sufficiently included among existing transit accessibility literatures. Most studies related to flexible form of transit are for accessibility of paratransit, which is of limited utility as the paratransit is restricted in use among a certain section of the society, especially for the elderly who usually form a small percentage of the commuter population (Ziari et al., 2007).

The level-of-service or performance of the feeder FRT/DRT shuttle is reflected by its ability to provide accessibility to its users to a given major transit line transfer stop/station. Accessibility is a scientific concept used in transport planning and plays a prominent role in policy making decisions (Geurs and Wee, 2004).

In literature review many researchers have proposed several methods to work out feeder routes. Shailesh et.al. (2013) used a gravity based potential accessibility and proposed an expression for the feeder network design to enhance the accessibility of the main system. He used the set up and corresponding equations for fixed route transit policy for a feeder service which was proposed by Quadrifoglio et. al. (2009) and assessed an expression for feeder design to for accessibility maximization.

Ridership increase for the major transit is expected if the feeder transit provides passengers a timely access to these transfer stops. The lesser the travel time per passenger, the greater the accessibility is (Bhat et.al. 2013). For the FRT, the travel time is easily computed for each travel loop of FRT shuttle beginning and ending its journey from and to the terminal, respectively, over a known number of stops.

2.4.1 **Feeder Bus Network Design Problem**

Feeder bus network design is the first and most important step in bus transport planning procedure and is solved by many researchers. The network design problem consists of determining a set of bus routes in a specific area, through the given travel demand, the area's topology characteristics, and set of objectives and constraints (Guihaire et.al. 2008).

Feeder routes link residential complexes to railway stations (Kim et.al. 2007). A good design of route network can increase the efficiency of the feeder bus system and decrease the total cost of supplying the transit service.

The users would like to have a bus network with more coverage area and high accessibility in the service area. Their perspective of a good service area is a feeder network with more direct through trips and highly demand satisfying. On the other hand, the operation's costs should be reduced by keeping the total route length within a certain bound. Thus the main challenge of the route network design is to be able to give a good and efficient alternative at a reasonable computation time. The feeder route network design problem can be solved by building initial solution using the contraction algorithm, followed by improving the existing solutions by means of applying a local search algorithm. One of the construction heuristics for building initial solutions is a sequential building method, proposed by Kuah and Perl (Kuah & Perl 1989). This method is adopted from sequential saving approach for Multi-Depot Vehicle Routing Problem (MDVRP). In another study Martins and Pato (Martins & Pato1998) expanded the research by Kuah and Perl (Kuah & Perl. 1989) and created the initial solution by applying the sequential savings. Their research suggested a two-phase building method to generate the initial solution. Shrivastav and Dhingra proposed Heuristic Feeder Route Generation Algorithm (HFRGA) (Shrivastav & Dhingra 2001). This algorithm was greatly guided by the demand matrix developed by Hadi Baaj and Mahmassani (Baaj & Mahmassani 1995). Metaheuristic methods are also applied for initial population. Genetic algorithm (GA) for an initial population at random was also used (Chien et al. 2001). Kuan et al. (Kuan et.al. 2004&2006) employed the concept of delimiter, proposed by Breedam (Breedam 2000). Pradhan and Mahinthakumar on their paper described parallel implementations that includes performance analyses of two prominent graph algorithms (i.e., Floyd-Warshall and Dijkstra) used for finding the all pairs shortest path for a large-scale transportation network(Pradhan & Mahinthakumar, 2013). Their article also includes the derivation of the computational time for the different parallel implementations of these two graph algorithms.

The various techniques used in the feeder bus route generation is indicated in Table 2.2. In Table 2.2, "M" stands for "mathematical," "H" for "heuristic," and "Me" for "metaheuristic." After building initial solutions, improvements can be implemented on the routes. There are a lot of optimization methods to improve the solutions.

Simultaneously several studies have been done also for the coordination of feeder services with mass transit alternatives (e.g. commuter rail, Bus Rapid Transit), especially using small capacity vehicles as the Minibus (Bellini, Dellepiane, & Quaglierini, 2003; Brake, Mulley, Nelson, & Wright, 2007; Brake, Nelson, & Wright, 2004; Hidalgo & Graftieaux, 2008).Some authors have been introducing optimization solutions to design these feeder bus services using Mixed Integer Linear Programming (MILP) approaches. There are several different formulations present in the literature, some focusing more in the coordination, optimizing simultaneously the bus routing and scheduling and the train timetables at a specific station (Chien & Schonfeld, 1998; Shrivastava & O'Mahony, 2006; Verma & Dhingra, 2006), while others considered the timetable of the high capacity mode as a constraint to which the minibus feeder service has to adjust (Mohaymany & Gholami, 2010; Wirasinghe, 1980). Chowdury & Chien (2002) focused on the estimation of the optimal headways for transit routes and slack times for coordinated routes of an intermodal transit system (bus and rail).

2.5 SHORTCOMING PRESENT IN CURRENT RESEARCHES

The inspection of the literature regarding feeder service revealed that much of the work has been done by taking feeder network design problem as an optimization problem, using techniques like computer programing, fuzzy logic, simulation models and genetic algorithms. Whereas an optimization problem is the problem of finding the *best* solution from all feasible solutions. Large number of studies is available for problems related to scheduling of public transport modes, optimization, simulation and coordination. However all of the existing researches present modelling feeder routes for a particular station and then propose to use the same methodology for each station separately. This results into repetitive modelling exercise. The shortcoming associated with these modelling exercises is the method of problem solvation. The assignment of route generation points is done prior to the route development or prior to the application

Table 2-2 Feeder Route Generation Methods in the Literature

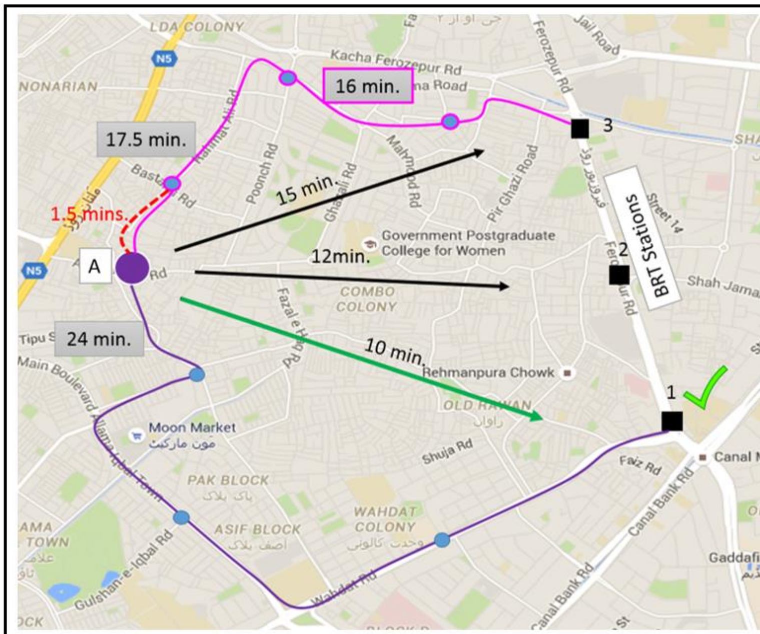
References	Initial Building Methods	Specify
Kuah & Perl, 1989	H	Sequential savings
Martins & Pato, 1998	H	Sequential savings and two-phase
Shrivastav & Dhingra, 2001	H	HFRGA, Dijkstra’s algorithm
Chien et al., 2001	Me	Genetic Algorithmm
Kuan et.al., 2004 & 2006	H	Delimiter algorithm (Breedam, 2000)
Shrivastava and O’mahony, 2006	H,	K-path algorithm (Eppstein, 1994)
Shrivastava and O’mahony, 2007	H	K-path algorithm (Eppstein, 1994)

Shrivastava and O'mahony, 2009	H	K-path algorithm, (Eppstein, 1994)
Shrivastava and O'mahony, 2009	H	Dijkstra's algorithm
Mohaymany and Gholami, 2010	Me	Ant Colony Optimization (ACO)
Gholami and Mohaymany, 2011	Me	Ant Colony Optimization (ACO)

Source; Mohammad et.al. 2014

of a certain modelling technique. These route generation points are assigned to a certain station by the decision maker which includes human preconceptions and biases. The criteria for selecting certain points for a specific is the shorter travel time. But in reality, one point may has shorter travel time from a given station and so is considered in the influence area for that station, may not has shorter travel time when inserted in the route generated for that station. On the other hand that node may be connected to any other route, generated for any other station and by doing so, its travel time may become shorter and generated

routes may become more optimized and improved in terms of travel time as illustrated in Figure 2.1 . This problem remains unknown, unless and until station wise approach is adopted. It can only be resolved by considering consecutive multiple stations simultaneously, and working out the optimized routes all at one stage. Previously in all the approaches, this issue has been unnoticed and is inherited in the generated routes. This research aims to tackle the said problem by improving the conventional approach for feeder network design. The improved approach will generate improved optimized results than the conventional one.



'A' is a route generation node that can be accessed by station 1, 2 or 3. Based on the travel time calculations, station 1 is found to be nearer than others, therefore 'A' is considered in the route generated for station 1. However when A is put in the route generated for station 1, its travel time is no more same rather than increased. This is due to the fact that initially it is selected based on direct travel time but actually this point will not be served directly but it would be a part of route which may alter the situation. .On the same time 'A' comes out to be only 1.5 minutes away from the terminus (or any other) node of another route viz. generated for station 3. Now if A is inserted in station 3's route, its travel time will be much reduced i.e. from 24 minutes to 17.5 minutes. This issue can only be resolved by considering multiple consecutive stations simultaneously, so that insertion of appropriate nodes in a route to get maximum optimized routes would be achieved.

Figure 2.1Illustration Showing Short Coming of Current Route Generation Practices

2.6 DEFINITIONS OF VARIOUS TERMINOLOGIES USED IN THIS STUDY

Feeder service

It is designed to pick up passengers in a locality and take them to a transfer point where they can make onward journey on the main service.

Network

It is an n arrangement of intersecting lines/routes either horizontally, vertically or diagonally that makes one complete system.

Service area/ Coverage

It is an area covered by a particular bus stop within walking distance from that stop. Or it is the area for a bus stop within which one can access that bus stop by walking.

Access and Egress modes

These are the vehicles one opts from origin/residence to the mass transit station and then from station to the final destination/workplace.

Paratransit

Any type of public transportation that is distinct from conventional transit in terms of flexible schedules, vehicle and routes.

Town

A **town** is a human settlement larger than a village but smaller than a city. A thickly populated area, having fixed boundaries and certain local powers of government.

Central Business District (CBD)

A Central Business District (CBD) is the commercial and business center of a city. In larger cities, it is often synonymous with the city's "financial district".

Feeder bus

Feeder bus services are designed to pick up passengers in a certain locality, and take them to a transfer point where they make an onward journey on a main service. This can be another bus, or a rail based service such as a tram, rapid transit or train. Feeder buses may act as part of a wider local network, or a regional coach network.

Chapter 3
RESEARCH METHODOLOGY AND STUDY AREA CHRACTERISTICS

It is evident that accessibility is one of the most supporting strategies for the successful implementation of any mass transit system. However increasing accessibility results in various measures that may be applied after carefully examining the existing scenario and needs. The methodology adopted in this research thoroughly examines and evaluates the current scenarios and then proposes a realistic feeder design that sets well as per the local area considerations. This chapter outlines the research framework, the hypotheses, data collection, the variables and the models used in this dissertation. The background of the study area and its characteristics are also the part of this chapter.

3.1 RESEARCH METHODOLOGY

In order to achieve the desired goal of the research a detailed methodology was formulated. Following is the brief description of the various tasks that were accomplished during the research work:

1. Initially it is compulsory to understand the operation of BRT, around the whole world, particularly in developed countries to discover the underlying realities that make their system fully efficient and utilized. For this purpose a detailed literature review was done. Several feeder network design methods to enhance accessibility were studied to find out the most suited for the given study area.
2. The current modal share to access/egress the BRTS was developed based on the field surveys. Based on the modal share results, the modes using as feeders were examined separately. The purpose of evaluating the existing feeder mode choices was to know their sufficiency and efficiency as feeder (see chapter 4).
3. For public buses, GIS based spatial analysis tool is used to examine their service area/ coverage (secondary data source). Few service quality attributes were empirically selected, against which current feeders were evaluated qualitatively. Commuters are interviewed against these attributes. This step revealed the current scenario of feeders (see chapter 5).
4. The effect of current feeders' condition over BRT accessibility is evaluated through SEM. Furthermore potential of a regular feeder bus is highlighted by adding it as endogenous latent in the model (see chapter 6).
5. For the proposed regular feeder bus, city is analyzed town by town to identify the areas that are most feasible for having a regular feeder service. Land use factors were considered for this decision making (see chapter 7).

6. The optimized feeder routes are generated by applying GA. For this purpose two approaches are adopted; one is the conventional one and the other is the improved one (see chapter 8).
7. Finally the research target of feeder network design is achieved by selecting improved optimized approach.
8. To achieve the research goal there is a need of quality data. The primary data for the research was taken from two kinds of field interview surveys (2015); one conducted at BRTS stations and for other the location is nearby selected offices, activity centers and hubs. The secondary data was also proved very helpful for spatial analysis, for analyzing few land use factors of the study area and for the development of feeder routes; and it was assessed from Lahore Urban Transport Master Plan Study done by JICA in 2012 (JICA, 2012)

3.2 CHARACTERISTICS OF STUDY AREA: LAHORE CITY

3.2.1 Pattern of Population Growth and Urban Land Development

Lahore is the second largest city of Pakistan, and cultural and educational capital of the country. It has grown along the historical route of Grand Truck (GT) road linking Central Asia with the sub-continent. Figure 3.1 shows the map of Lahore Metropolitan Area (LMA), which covers an area of 1792 Km^2 and has population approximately 8.65 million (JICA, 2012) as shown in Figure 3.2 . The recent JICA (2012) study reports that current 8.65 million population of Lahore has 1.8 million households, employed residents is 2.7 million, average household income per month is 20,000 PKR, average income per capita per month is 3,500 PKR, household car ownership 18% and household motorcycle ownership 43%. Lahore can be classified into three population density zones: high-density inner zone, medium density intermediate zone and low-density outer zone. Population is mostly concentrated around the old city area in a concentric fashion. Population density varies almost from 450 persons per hectare in the inner zone to 50 persons per hectare in the outer zone. Major developments occurred along major arterial roads i.e. linear development. Around 70% of population is living within radius of 7-8 km from city centre. The regulations are still very weak in controlling the land use and development despite of several development plans. Lahore has high potential of transit development considering the number of trips generated due to high-density development in inner zone. However, population density in Lahore is still considerably lower than similar cities in Asia (JICA, 2012). It is concentrated with many educational institutions and medical facilities as well as surrounded by industrial zones. There is high trend of migration of people to Lahore city for education, jobs as well as to enjoy better living facilities. Age groups 15-19 and 20-24 year form the peak for both male and female as shown in Figure 3.3. The literacy rate of Pakistan and Lahore is around 55% (CIA, 2009) and 74% (GoP, 2012) respectively.

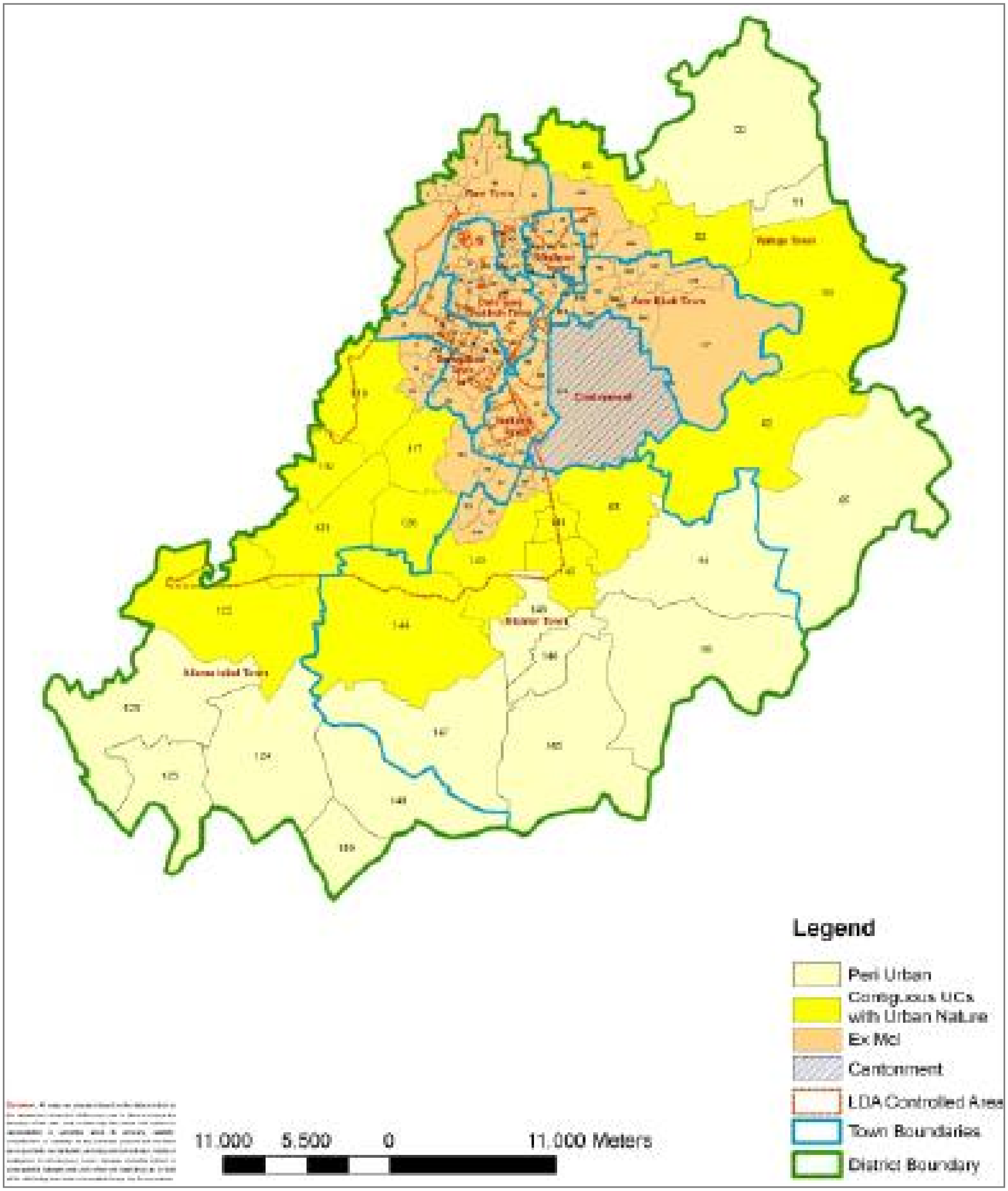


Figure 3.1 Map of Lahore city

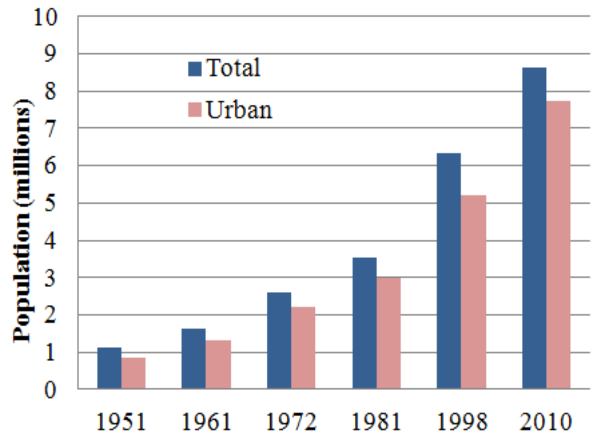


Figure 3.2 Total and urban population growth (JICA 2012)

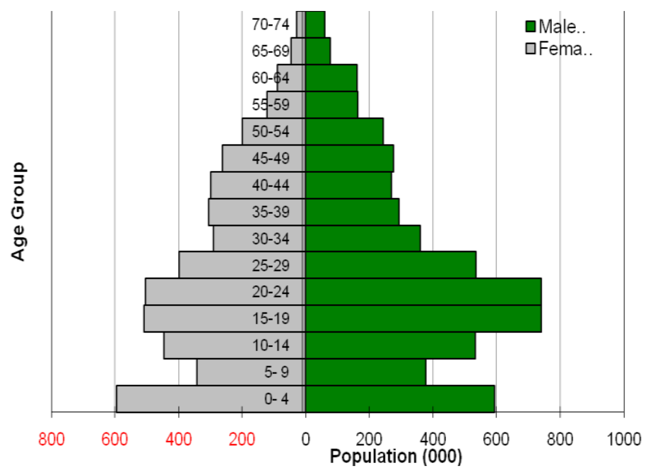


Figure 3.3 Male and female age structure (JICA 2012)

3.2.2 **Vehicle Ownership Growth and Modal Share**

The vehicle growth rate has reached to 17% per year between 2004 and 2008 in Lahore, increasing the traffic congestion on the roads. Now-a-days, Lahore residents are showing a high trend for motorcycles ownership, which were tremendously increased by 483% or 136 units per 1,000 residents in 2008. Figure 3.4 shows the pattern of vehicle ownership growth in Lahore. The main reasons of increase in automobile ownership are banking leasing policy of government, status symbol, changing lifestyles, increase in income, low ownership, and usage cost. Government policy to import used cars from developed countries (e.g. Japan) also affect the car ownership and its usage. Figure 3.5 shows the modal share of Lahore city. The share of car ownership is more in low to medium density areas, whereas share of motorcycle ownership is more in medium to high-density areas. The trip rate of male and female in Lahore is 1.32 and 0.53

respectively (JICA, 2012). According to recent JICA study regarding Lahore urban transport master plan walking is major mode of travelling regardless the type of trip or trip distance.

Generally, it has been observed that local people do not like to walk or use bicycle even for shorter trip. Almost more than 13.5 million motorized trips are generated in Lahore (Urban Unit, 2007). People prefer to use motorcycle even for shorter trip, and use it as a family mode. Motorcycle almost accounts for 45 % of road traffic (Urban Unit, 2010), whereas 22.4 % of modal share (JICA, 2012). The share of car is almost 9%, which is likely to be increased if attention is not given to improve public transport and impose measures to reduce usage of private vehicle. Use of motorcycle and car also threatens the safety of pedestrian and bicycle users.

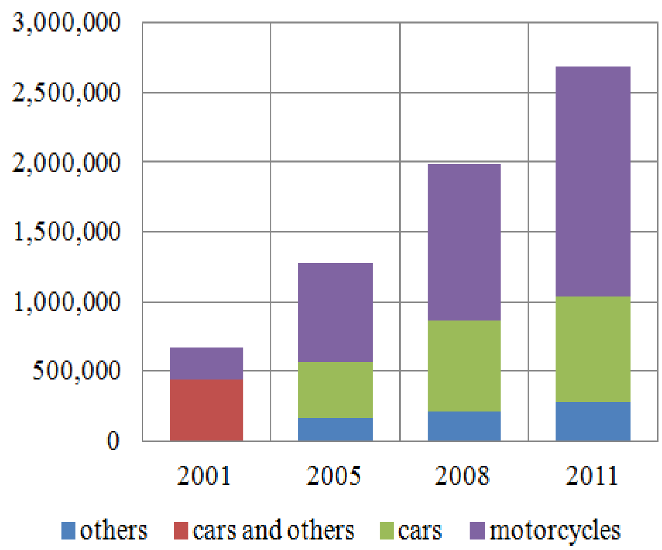


Figure 3.4 Vehicle ownership growth (source: GoP)

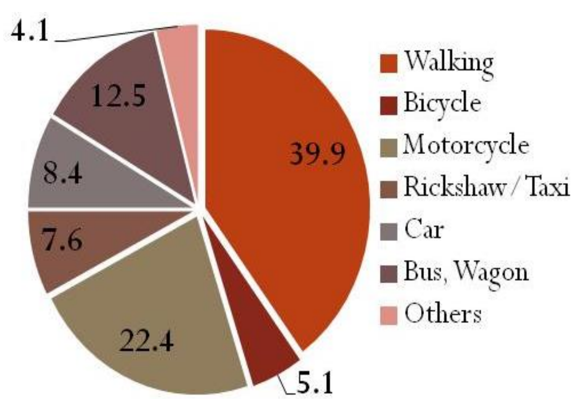


Figure 3.5 Modal share (JICA 2012)

3.2.3 Overview of Historical Urban and Transportation Development Plans

The Master Plan for Greater Lahore was prepared by the Housing and Physical Planning Department, Government of Punjab in 1966. In order to segregate the urban Lahore from surrounding towns a 24 km wide green belt was proposed. Construction of a ring road, a new road bridge on river Ravi, up grading of major roads, and provision of underground and multi-storey parking lots in the central area was proposed. A circular railway system was also proposed for commuting traffic. However, due to lack of development control, the city continued to grow linearly along radial routes, and the Greater Lahore Master Plan failed (Imran and Low, 2005, Hameed and Nadeem, 2006).

Lahore urban development and traffic study, 1980 (LUDTS) was conducted by Halcrow Fox UK, and it was the first attempt to plan the city growth, and prepare an integrated development and transportation infrastructure plan for the year 2000 with the help of World Bank. The study identified issues related to traffic characteristics, urban land and road infrastructure development, institutions, and public transportation operation and management. Other main proposals of this study was to construct the "Southern by Pass", renamed as "Lahore Ring Road". The "model urban transportation system" in Lahore was completed in 1980 with the financial and technical grant of the Volvo International Development Corporation. As a result of this study, 350 Volvo buses were gifted by the Swedish Government to Lahore. However, after operation of couple of years, bus system in Lahore collapsed because of the organizational inefficiency of the government (Imran and Low, 2005, Hameed and Nadeem, 2006).

1991 comprehensive study on transportation system in Lahore was conducted by JICA consultants with the assistance of Lahore Development Authority (LDA) & Traffic Engineering and Planning Agency (TEPA). The study objectives were to formulate a transportation master plan for the study area for 2010, with intermediate action plans for year 2000, and to conduct feasibility study of selected mass transit system. Beside urban and road development plans, JICA proposed rail mass transit including the construction of the light rail transit (LRT). This project has four lines i.e. green line, blue line, orange and purple line (ADB, 2008). So far, this project did not implement due to some financial and political issues.

Lahore urban transportation master plan 2020-2030: This study was conducted in 2010-2011 by JICA for Government of Punjab with following objectives: to formulate an urban transportation master plan for the study area up to the year 2030 and action plan for the identified priority projects up to the year 2020, and to provide assistance to strengthen the institutional and administrative capacity of the Government of the Punjab. According to report, the total travel demand for public transport in 2030 would exceed 5 million. In this master plan, JICA has proposed major public transportation improvements, which include three lines of rail mass transit in spite of four lines as in 1991 master plan and Bus Rapid Transit (BRT) on four major arterials (JICA, 2012).

3.2.4 Structure of Existing Public Transportation

The public transportation network in Lahore is currently under-developed, highly fragmented, inadequately managed, and inefficient. More than 800,000 passengers are using public transportation in Lahore where about 800 high occupancy buses only are operating by almost 13 private companies. Among various attempts to improve the overall transport conditions of the city, the introduction of Bus Rapid Transit System (BRTS) in year 2013, which is also called as Metro Bus came out to be the most feasible and attractive for the travellers. The corridor of BRTS was selected based upon the recommendation made by JICA in master plan study. But still, there is a big gap between the demand and provision of an efficient and environment friendly public transportation, since BRTS is the only one line running in the city which has high travel demand. Currently, other public transportation services are providing by many private bus operators i.e. Daewoo, Premier Bus Service, First Bus, Niazi, Malik, Baloch, and Futon (Chinese) etc. The urban bus operation is regulated through Lahore Transport Company (LTC), setup by the Government of Punjab in 2009. As per the master plan data sources, there are almost 53 planned routes for buses and 48 routes for wagons or minibuses along with the concentration of motorcycle rickshaws on various routes. However the operation of mini buses/ vans has reduced considerably, almost equals to none. Several bus routes have also become non-operational, resulting in 30 planned bus routes under LTC (Figure 3.6). Premier Bus Services, owned by the Beacon house Group, was started in 2003. It provides premium transportation services to the public of Lahore, with almost 250 buses running on exclusive routes. Daewoo Korean owned company operates four routes within the Lahore city and two suburban routes connect urban parts with two nearby districts i.e. Gujranwala and Sheikhupura. Daewoo bus service has almost 76 buses; they are air-conditioned and provide better comfort to the passengers. Other operators run their buses only on few routes. The Para-transit service mainly comprises of motorcycle rickshaw (qingqi) and auto-rickshaw.

Due to rapid motorization and increase in traffic volume over the last two decades, the road network has become congested which increases travel delays and reduces bus travel speeds, implying a less competitive public transportation network, especially in the Central Business District where commercial and trading activities are concentrated. Current public transportation services other than BRTS, are suffering greatly due to irregularity. Efficiency is acceptable on certain routes but reliability is poor, there is no scheduling at all. Many vehicles are operated without valid license, with an estimated 25% or more of wagons/ minibuses with no valid license (JICA, 2012). Many wagons and coasters drivers do not follow the authorized route, and sometimes do not complete the full route journey. The inefficiency of public-owned public transportation has led to the multiplication of illegal operation and forcing the private vehicle ownership even higher. User-friendly, economical, and affordable public transportation development is the first demand of most of the residents. Moreover, public transportation organizations in Lahore have a long history of deficiency in professional, administrative, and financial capacity to manage public transportation service. In the absence of human resources, coordination, research, and financial capacity of public transportation institutions, public transportation has now become fully the privilege of the private sector. The incomplete routes, high fares, fewer buses, gender discrimination, and even absence of buses in some places are common in the urban areas. Whole public transportation is grossly mismanaged with least objective of service provision, limited and inadequate condition of public transportation facilities.

3.2.5 City's Bus Rapid Transit System (BRTS)/ Lahore Metro Bus

Over the past 15 years the rapid growth in population and vehicle ownership has steadily worsened traffic congestion. Vehicle registration has increased from 56 to over 116 per 1,000 inhabitants. Cars have increased over the same period from 13 to 35 per 1,000 inhabitants and are now increasing at the rate of 10 to 15% per annum. With a population predicted to rise to over 15 Million by 2015 and the economic growth running at the rate of 5% p.a this situation would only get worse, in the absence of any proposed transport infrastructure improvements.

In order to cope with the ever increasing traffic congestion on the Lahore road network, JICA carried a comprehensive study on the transportation system in Lahore. The study formulated a transportation plan for the city for next 20 years. The master plan identified following two corridors requiring a Mass transit system

Ferozepur Road Corridor 28.7 Km

Multan Road Corridor 12.4 Km

The public transport demand on the above said corridors had increased so significantly that a normal bus system would not be able to cater the public transport needs on the said corridors. The only solution to this was development of a "Rapid Transit System". For this purpose the Government of Punjab established Punjab Metrobus Authority (PMA) for construction, operation and maintenance of mass transit system. This authority has established the Metrobus System Line-1 (Ferozepure Road) in Lahore, and is the first system to be operated by PMA. MBS Line-1 is approximately 27 KM long running in the North-South direction through the heart of Lahore (Figure 3.7). Key locations throughout the city are targeted to allow maximum number of citizens from surrounding areas to avail the bus services. Initially, 27 stations were planned and built along the MBS corridor, which have been designed keeping in view the needs of the passengers. The expected socio-economic benefits of the system were:

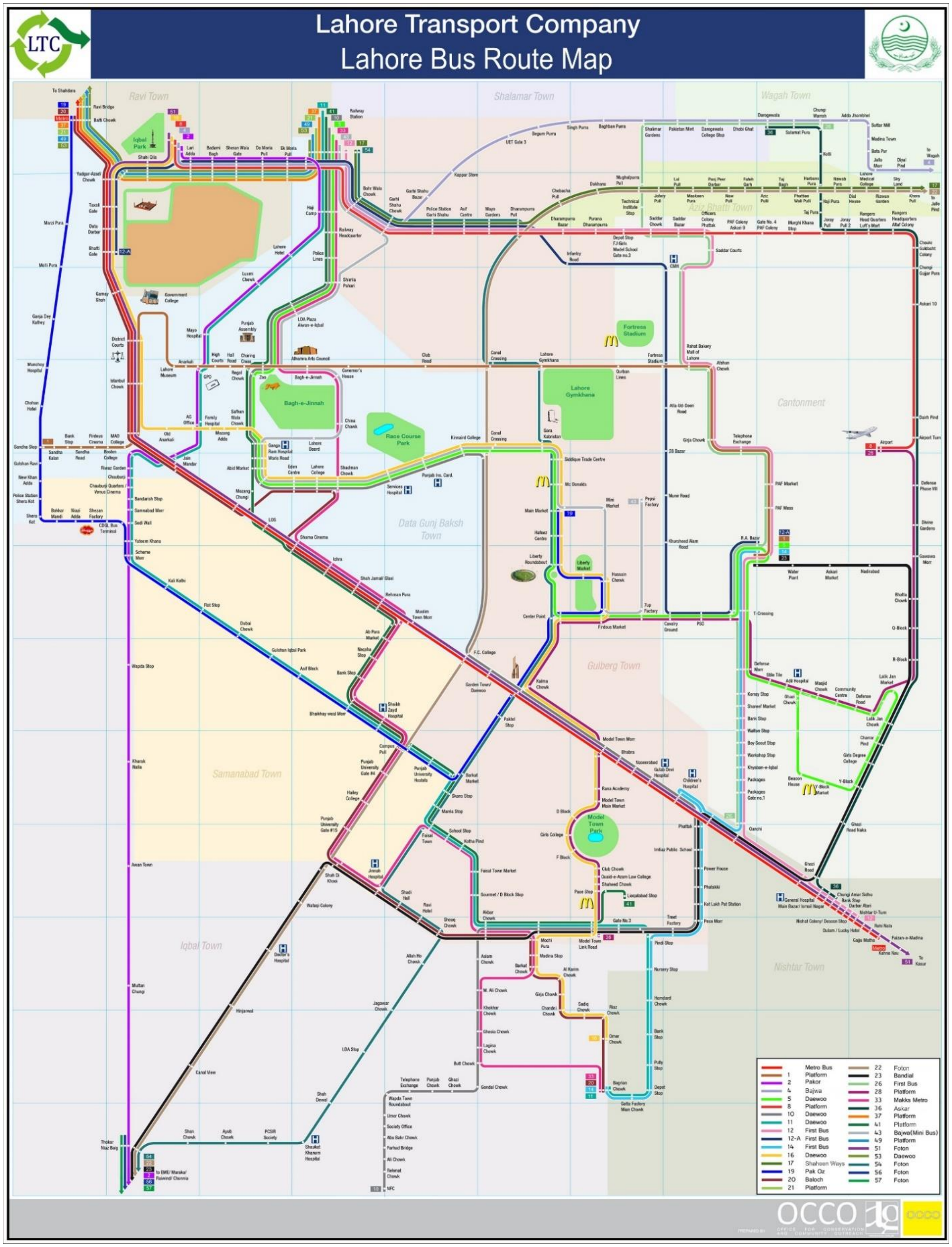


Figure 3.6 Lahore bus route map

i. Savings in Vehicle Operating Costs (VOC) and maintenance costs
ii. Decrease in travel time and traffic congestion
iii. Reduced strain on accident and emergency response system
iv. Smoother and safer intra-city travel
v. Preference of use of buses on personal vehicles will be fuel efficient
vi. Increase in economic activities
vii. Increase in employment opportunities during construction and post-construction period
viii. Additional revenue via advertisement buses
ix. Maintain standards of safety and speed and manage traffic equitably, which may reduce the economic cost of travel on the aforementioned traffic routes.
x. Reduce traffic load from the areas of high activity, providing ample capacity on the main boulevards to cater for the prospective growth in the city traffic.

This system connects the two ends: Gajjumatta (South) and Shahdara (North) of the city with a luxurious, efficient, and comfortable mode, in the form of articulated buses, running on the exclusive fenced bus lane.

The operation of the system is fully ITS based, which provides signal priority over the intersections. The fleet size has reached 80 articulated buses starting from 64 and the design speed is assumed to be 40KPH. Thorough this system, this 27 kms distance is covered within just 45 minutes which seems quite impossible under prevailing system of congested traffic in the city. The timetable for these modern busses is framed in such a way that the new bus will be available at each station after every 3 minutes. The latest ticketing system is also being introduced at each Metro station, along with other necessary facilities for the passengers. Another important feature of the project is the construction of overhead bridges, almost one at every kilometer of the main carriage way in average, for the pedestrians. The bridges are accomplished with automatic staircases to facilitate the passengers. Parking places at various stations have also been included with the corridor, to facilitate the parking of the public vehicles of the passengers, who opt to reach station on their own vehicles to travel on a Metro bus for a long distance.

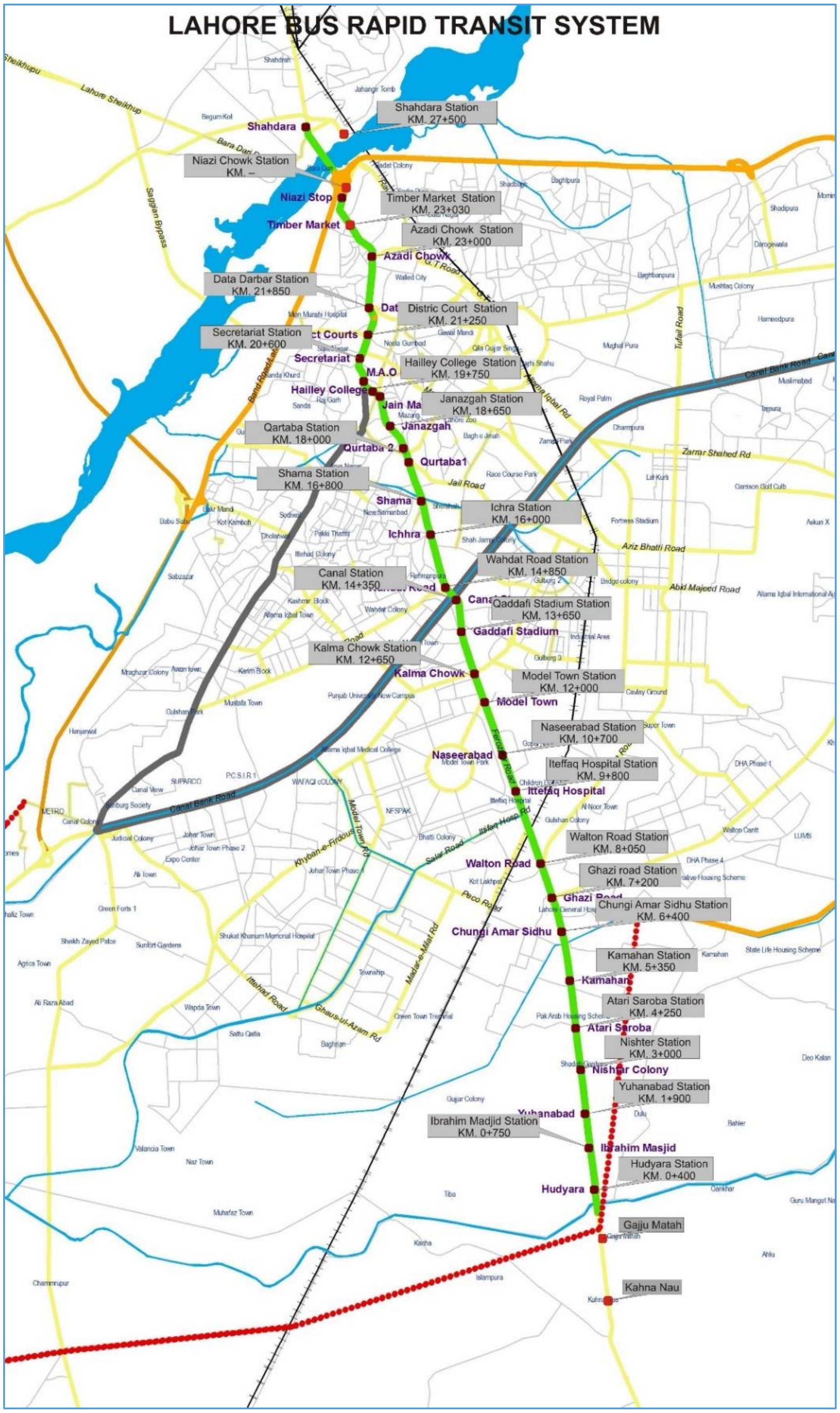


Figure 3.7 Lahore BRTS map

However despite of all the merits and facilities, the major associated flaw is that it is a stand-alone service that does not integrate with the rest of the city. The system is not designed from a network perspective considering other modes too. Neither it is integrated nor provided with any kind of feeder service. Although master plan study suggested that the primary network must be supplemented by the secondary and feeder service, but no attention was paid towards the secondary service. The absence of any regular feeder service made the system less attractive, since accessing the system from (east-west) other parts of the city and then egressing towards the destination is still remain a question. This fact yields a higher percentage of those users who can access/egress the system through walk. The other modes available to be used as feeders include paratransit and public buses (in case of no regular feeder). However the quality of travel in these feeders has no match with that whom these are feeding to. Though the system is located on one of the city's main arterials that provides direct access to most of the workplaces, offices, hubs, activity centers and commercial areas but even then accessing the system from one's origin/house needs to be considered.

3.2.6 Current available Feeders for BRTS

This section is to give an overview about the auto access of BRTS. As it was discussed before, BRTS is designed solely as a bus line, for the feeder part it is neither provided nor integrated with the existing other public transport modes. Although the other modes have no match with the BRTS in any aspect (will be discussed later), but in the scenario where there is no other better choice available to the public, commuters have to use these. As per the current situation the modes available for feeders are either public buses or paratransit (Auto rickshaw and Motorcycle rickshaw). Few BRTS stations are provided with Park and Ride facilities, and so therefore can be accessed by private vehicles also, by parking the vehicle on these P&R sites and then making further travel through BRTS. Following is the vehicles' overview that are available for being used as feeder:

Public Bus

According to the master plan study, city owns 53 planned bus routes, but now only 30 bus routes are in operation. Several bus routes have been closed due to the operational issues combining the fact that BRTS takes a significant share now. All of these buses operate on the major roads of the city, since these major arteries do not offer significant mobility due to increased congestion in the city. Also the collector roads are much congested that cannot take the load of these buses anymore. These buses operate on the fixed routes and have certain fixed stops along the route, and have fixed fare. However there is no schedule or timetable of these buses. The waiting time of about 15-30 minutes is found common, however for some buses it exceeds from 30 minutes. Their route length and distance between the stops varies ranging from 12 km to 50 km and 16 to 56 number of stops respectively. Their major user class belongs to low income group mainly, which have no other choice and transit captives. Most of these buses offer poor comfort level to passengers, in terms of seating/ standing facilities, including the way these are being driven since the drivers are not properly educated and trained. This fact also led to the higher percentage of accidents associated with the public buses. Not only had this, the overcrowding within the buses, due to their lower frequency, resulted in increased pick pocket crime rates during traveling (Figure 3.8).

Paratransit

Paratransit in another significant mode available in the city. City holds two kinds of paratransit one is Auto rickshaw and the other is Motorcycle rickshaw. Auto rickshaws are hired on demand only, and so don't follow the fixed routes. They are mostly availed by females and old aged people and have higher fares. The fare is not fixed and depends on the distance and the bargaining between the passenger and driver. Though these can be used for access/egress, but their use is limited owing to higher travel cost.

On the other hand Motorcycle rickshaws also known as Qingqi, have lesser fares and therefore mostly used as feeder mode. During last years these qingqi have made deeper in roads and came out to be a competent for buses. They have certain routes and supposed to use the bus stops as a stop but actually they stop and take the passengers from any point on the way. Their operation is quite flexible and so offer high mobility but with the tons of associated risks and dangers. These are supposed to operate on link roads only, where buses cannot move around, but they are operating on arteries too. Most of these are unregistered, don't own any route permit and fitness certificate and operate in an illegal way. High noise, bumpy and uncomfortable travelling, wild and rage driving are the common observations. Drivers are found to be underage and almost all belong to low income group. Government has decided many times before to ban these based on the facts of congestion, safety hazards, increasing pollution but could not implement yet due to the strong resistance

Figure 3.8 City's Conventional Transport modes

from their drivers. In some areas of the city, these qingqi are not allowed to go through and banned. Not only this, city's environmental department claimed these vehicle, responsible for city's 80% environmental pollution.

Irrespective of several demerits, high percentages of commuters prefer them due to their flexibility and so time saving. Infrequent operation, longer waiting time, overcrowding, limited service area coverage and poor law and order situation in the public buses have compelled the commuters to use these qingqi (Figure 3.8).

Note that, in this study the term paratransit will only deal with 'Motorcycle rickshaws (Qingqi).

3.3 DATA EXPLORATION

In order to achieve the desired objectives of the research, the data was obtained from the three sources: one is from Lahore Urban Mater Plan (LUTMP) study that was done by Japan International Cooperation Agency (JICA) in 2011-2012, the other was daily ridership data, at each station from Punjab Metro Bus Authority (PMBA) and the last one was through field interview surveys, specifically conducted for the research. The data from masterplan study provided the demography of the whole city, socio-economic details and land use characteristics. The details like overall travel pattern and the percent trips contributed by each town of the city further helped to identify the areas that has potential to be served by regular feeder service (see chapter 4). However the master plan was prepared before the introduction of BRTS, therefore lacked in providing any specific BRTS relevant data, except the fact that plan suggested few most feasible corridors for mass transit system and the current corridors is one of these.

Two types of field interview surveys were conducted in Feb. 2015, to observe and analyse the current travel pattern. For the first type only the BRTS stations were targeted, and so the respondents were the BRTS users. And for the second type, the respondents were the workers working in offices, activity centres and commercial areas that were located alongside the BRTS corridor (Figure3.6). The main objectives were to assess the current feeder modes used by the BRTS users, evaluate these modes qualitatively and quantitatively. For evaluating the quality of existing feeder modes, specific service attributes were selected empirically and the Likert was used. The Likert Scale is an ordinal psychometric measurement of attitudes, beliefs, and opinions. For each attribute, the degree of satisfaction of the users is measured by providing him multiple choices ranging from very good to very bad. This scale has following merits in conducting questionnaire survey: most universal method for survey collection; therefore, they are easily understood, responses are easily quantifiable and subjective to computation of some mathematical analysis, it does not force the participant to take a stand on a particular topic and provides the flexibility to respondents in answering the questions (it does not require the participant to provide a simple and concrete yes or no answer), responses are very easy to code when accumulating data since a single number represents the participant's response. Likert surveys are also quick, efficient and inexpensive methods for data collection. Few dichotomous questions were included (for non-users) to know the willingness to use the BRTS, if provided with regular feeder service, and to pay for that service. These interview surveys are described in details in subsequent sections.

3.3.1 Questionnaire Design & Field Survey- Type I

The core objective of this survey is to assess the current travel pattern through BRTS, from origin to the final destination. The main focus was the first and last part of the travel i.e. how do the access the station from their origin and then how do they make their egress trip which is from station to the destination. In addition to this the quality of the mode being used, was also evaluated in terms of few service attributes, for which their consensus was asked using Likert scale. The survey locations were BRTS stations, and so the respondents are definite users. Since the type of the survey was intercept interview survey, therefore the questionnaire was kept comprehensive and to-the-point. Five survey locations (stations) were selected in such a way that it would not only cover the whole corridor: central part and the two bounds, but also few of those stations which are provided with parking facility (Figure 3.9). The survey was conducted in Feb. 2015, during morning and evening peak hours, 7:00-10:00 and 16:00-19:00, respectively, resulting in 300 samples. The questionnaire was divided into following three parts:

I- **Personal information:** It includes the individual characteristics. The respondents were asked about their demography: gender category, Income level and most importantly about vehicle ownership. Since during last five years, vehicle ownership rate has been multiplied significantly, therefore it is important to know those BRTS users who own their private vehicle but still using BRTS. The information of one's income level also helped to draw the inferences about BRTS's users classification based on the income level, as it was claimed that BRTS will not only attract the lower income group but also the middle and higher income groups.

II- **Trip information:** This section covers the details of the trip, access and egress both. The respondents were asked about their origin/ destination places, trip purpose, and frequency of using BRTS. Trip attributes like distance, time and cost incurred for the feeder mode were also inquired. Assessment of the feeder mode being used for access and egress, was also done. For this purpose, six service quality were empirically selected, and the respondents were required to show their level of satisfaction by selecting the most appropriate response e.g. very good, good, fair, bad and very bad. These service quality attribute include service/ route reliability, travel time, travel cost, comfort, safety & security and environmental aspects (pollution).

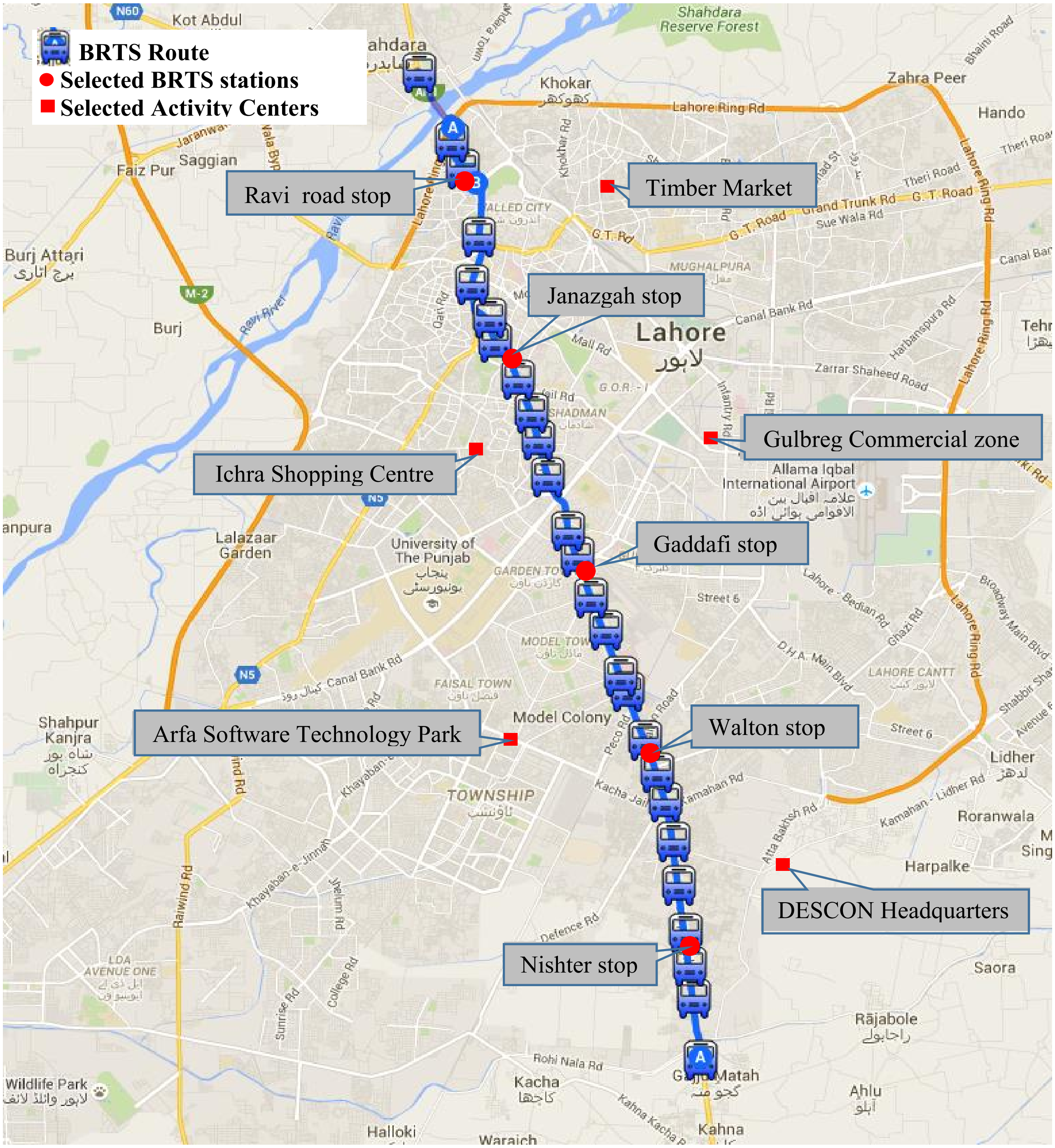


Figure 3.9 Selected BRTS stations and Activity centers for Field survey

III- **Willingness to pay:** In this section, respondents were asked about their willingness to pay for the feeder service which would be more reliable, efficient, frequent and comfortable. The purpose is to analyse the feasibility of starting a new feeder service, from the users' side, in terms of paying for it. The respondents who agreed to pay were also inquired about the maximum cost they can pay.

The contents of the questionnaire were kept short, keeping in view that travellers are reluctant to spare much time and answer long questions. The survey was conducted by university under graduate students, who were directed to make the respondents understand each service attribute, before giving an opinion.

3.3.2 **Questionnaire Design & Field Survey- Type II**

Another interview questionnaire survey was conducted at some selected activity centres, commercial areas, offices and hubs, located nearby or alongside the BRTS corridor. The focus of this survey was to capture only those commuters, whose workplaces/ destination is located along the BRTS corridor, in other words who can make their egress trip by walk, if they use the system Another concern for this survey was to capture other income classes also, than low income class only. Among the respondents there were mainly two types of commuters, BRTS users and Non-users. From the user's respondents, information about the access part i.e. from origin/home to the station was collected. Whereas, willingness to use the system, if it is provided with regular feeder service, was questioned from the non-users. The questionnaire comprised of following sections

- I- Personal information: The information about one's gender category, income level and the vehicle ownership was asked in this section.
- II- Trip Information: In this section, respondents were asked about their origin, main travel mode i.e. walk, public transport (BRTS, local bus or paratransit) or private vehicle (car or motorcycle). After knowing their main travel mode, this section is further sub-divided into two part: one was for BRTS users and the other was for non-users.
  - a. The BRTS users provided the information about the access mode, distance and cost for accessing the station. They also rated the service quality attributes of the feeder mode using Likert scale, as discussed before. Their willingness to pay for a regular feeder service, and how much they can pay additionally, were also questioned in this section.
  - b. Those respondents, who didn't use BRTS, provided the information about the distance of BRTS's nearest station from their origin/home and their willingness to use BRTS if a regular feeder service is started. Their willingness to pay for the feeder service was also inquired.

These surveys were conducted at the respondents' workplaces, so all the trips were work-based trips. Total 298 samples were collected from five places selected alongside the corridor.

3.4 APPLICATION OF STRUCTURAL EQUATION MODELING (SEM)

Collected data through questionnaire surveys was analysed for evaluation of influencing factors using structural equation modelling procedures. It is relatively a new methodology for multivariate analysis and its roots can be found in the 1970s. Researchers in the field of psychology, sociology, biological sciences, and market research are frequently applying this methodology for analysis of data and making inferences. Its application in travel behaviour research was started from 1880s. Structural equation modelling (SEM) is a statistical methodology that takes a confirmatory approach (i.e. hypothesis testing) to the analysis of structural theory bearing on some phenomenon. Typically, this theory represents "***causal***" processes that generate observations on multiple variables (Bentler, 1988). The term structural equation modelling tells two important aspects of the procedure: (a) that the causal processes under study are represented by a series of structural equations (i.e. regressions) and (b) that these structural relations can be modelled pictorially to enable a clear conceptualization of the theory. The hypothesized model can then be tested statistically in a simultaneous analysis of the entire system of variables to determine the extent to which it is consistent with the data. Estimation of SEM is performed using the con-variance analysis method. If goodness-of-fit is adequate, the model argues for the plausibility of postulated relations among variables; if it is inadequate, the tenability of such model is rejected (Byrne, 2010).

3.4.1 Description of SEM Model Specification

SEM models provide an efficient and convenient way of describing the latent structure underlying a set of observed variables. These models expressed either ***diagrammatically*** (path diagram) or ***mathematically*** via a set of equations, and such models explain how the observed and latent variables are related to one another. Figure 3.8 presents a general SEM model, which demarcated into different components. Generally, a statistical model is postulated based on knowledge of the related theory, on empirical research, or on some combination of both. Once the model is specified, plausibility of model is tested based on sample data that comprise all observed variables in the model. The primary task in this model-testing is to find the goodness-of-fit between the hypothesized model and the sample data. Generally, the structure of a hypothesized model imposes on the sample data, and then tests how well the observed data fit this restricted structure. It is very difficult to get a perfect fit between the observed data and the hypothesized model, therefore; there will necessarily be a difference between the two and this difference is termed as residual (Byrne, 2010). Therefore, the model model-fitting process can be written as follows in equation 3.1:

$$\text{Data} = \text{model} + \text{residual} \qquad (3.1)$$

Where; ***data*** represent score measurements related to the observed variables as derived from person's response comprising the sample, ***model*** represents the hypothesized structure linking the observed variables to the latent variables, and in some models, linking particular latent variables to one another, ***residual*** denotes the discrepancy between the hypothesized model and the observed data.

Latent versus observed variables: In the field of behavioural science, researchers are often interested in studying theoretical constructs that cannot be observed directly. These extracted phenomena are termed as ***latent variables or factors*** and represented by circle or ellipse as ξ_1, η_1, η_2, in Figure 3.10. Because latent variables are not observed directly, it follows that they cannot be measured directly. Thus, the researcher must operationally define the latent variable of interest in terms of behaviour believed to represent it. As a result, the unobserved variable is linked to one that is observable, thereby making its measurement possible. Assessment of the behaviour, then, constitutes the direct measurement of an observed variable, though the indirect measurement of an observed variable. The variable can be measured and have some measured scores as termed as ***observed variables or indicators*** of the latent variable and represented by rectangles or squares in a SEM model as X_1, X_2…., Y_1, Y_2…. in Figure 3.10.

Exogenous versus endogenous latent variables: It is easy in SEM model to distinguish between latent variables that are exogenous and those that are endogenous. Exogenous latent variables as variable ξ_1 in Figure 31are synonymous with independent variables; they "cause" fluctuations in the values of other latent variables in the model. Changes in the values of exogenous variables are not explained by the model. Rather, they are considered to be influenced by other factors external to the model. Background variables such as gender, age, and socio-economic status are examples of such external factors. Endogenous latent

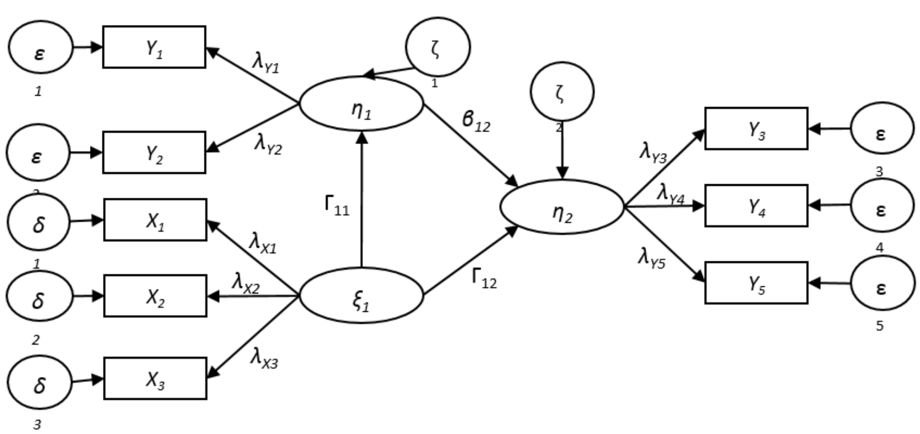
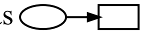
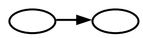
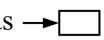
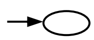


Figure 3.10 General Structural Equation Model or Path Diagram

variables as variables η_1 and η_2 in the model of Figure 3.10 are synonymous with dependent variables, and are influenced by the exogenous variables in the model, either directly or indirectly. Fluctuation in the values of endogenous variables is said to be explained by the model because all latent variables that influence them are included in the model specification.

Measurement versus structural model: The general SEM model as shown in Figure 3.10 can be decomposed into two sub-models i.e. a measurement model and a structural model. The measurement model defines relations between the observed and unobserved variables and is represented as  . This relationship is called as path coefficient for regression of an observed variable onto an un-observed latent variable. In other words, it provides the link between scores on a measuring instrument and the underlying constructs they are designed to measures. The measurement model, then, represents the CFA model. In contrast, the structural model defines relations among the un-observed variables. Accordingly, it specifies the manner by which particular latent variables directly or indirectly influence changes in the value of certain latent variables in the model. This structural relationship is called as path coefficient for regression of one factor onto another factor, which is represented as  . In path diagram, the measurement error associated with an observed variable is represented as  and residual error in the prediction of an unobserved factor as  .

3.4.2 Path Diagram and Mathematical Representation of SEM Model Estimation

Schematic representations of the models are termed as path diagrams. They provide a visual portrayal of relations, which are assumed to hold among the variables. A path diagram is actually the graphical equivalent of its mathematical representation whereby a set of equations related dependent variable to their explanatory variables. A general path diagram is represented in Figure 3.10 which describes its components using different symbols and notations. SEM tools consists of two main parts (i) latent variable model which describes the relationship between the endogenous and the exogenous latent variables and permit the direct assessment of model (ii) measurement model which depicts the correlation between latent and observed variables. Both models described above consist of basic equations that describe the relationship between the independent variables (Bollen, 1989, Byrne, 1998). Structural equation can be represented as:

$$\eta = \beta\eta + \Gamma\xi + \zeta \qquad (3.2)$$

Where

η = *(m x 1),* vectors of the endogenous variables

ξ = *(n x 1),* vectors of the exogenous variables

ζ = *(m x 1),* vectors of the random variables

β = *(m x m),* coefficient matrix for the endogenous latent variable

Γ = *(m x n),* coefficient matrix for the exogenous latent variable and its elements represents direct causal effect of ξ variables on η variables.

It should be noted that β and Γ are the structural coefficients of the model and the equation for the measurement model consists of:

$X = \lambda_X \xi + \delta \rightarrow$ For exogenous variables and $Y = \lambda_Y \eta + \varepsilon \rightarrow$ for endogenous variables

Where

$X = (q \times 1)$, vectors related to the observed exogenous variables

$\delta = (q \times 1)$, vectors related to errors associated with observed exogenous variables

$\lambda_X = (q \times m)$ structural coefficients matrix for the casual effects of the latent exogenous variables on the observed variables

$Y = (p \times 1)$, vectors related to the observed endogenous variables

$\varepsilon = (p \times 1)$, vectors related to errors associated with observed endogenous variables

$\lambda_Y = (p \times m)$ structural coefficients matrix for the latent endogenous variables on the observed variables

3.4.3 Sample Size Requirements and Model Estimation

Estimation power of SEM is affected significantly with the sample size and need significant attention. There are several suggestions from researchers for the minimum sample size; (1) a minimum sample size of 200 is required to reduce the biases to an acceptable level, (2) sample size should be at least 15 times the number of observed variables or at least five times the number of free parameters in the model in case of maximum likelihood estimation, and (3) with strongly kurtotic data, the minimum sample size should be at least ten times the number of free parameters (Golob, 2001, Raykov and Marcoulides, 2000). The fundamental principle of co-variance analysis is used for model estimation. The general strategic framework for testing structural equations, Joreskog (1993) distinguished among three scenarios, which he termed as strictly confirmatory, alternative models and model generating. The primary objective is to locate the source of misfit in the model and to find a model that better describes the sample data. Joreskog (1993) states that although specification may be either theory or data driven, the ultimate objective is to find a model that is substantively meaningful and statistically well fitting. The common model estimation methods include maximum likelihood (ML), generalized least squares (GLS), weighted least square (WLS), asymptotically distribution free (ADF) and un-weighted least squares methods. The most commonly used method is the maximum likelihood. This method maximizes the probability that the observed variances are drawn from a population that has its variance-covariance's generated by the process implied in the model, assuming multivariate normal distribution. The ML is assumed to be stronger with some limitations and yields good statistical estimates of parameters.

3.4.4 Assessment of Goodness-Of-Fit of SEM Model

The reliability of a SEM model is checked by indices of goodness-of-fit parameters. Following parameters were used in this study in order check the goodness-of-fit of models i.e. chi-square/ degree of freedom (χ^2/DF), Goodness-of-Fit Index (GFI), Adjusted Goodness-of-Fit Index (AGFI), Comparative Fir Index (CFI), Root Mean square Residual (RMR) and Root Mean Square Error of Approximation (RMSEA). Different researchers in the field of statistics have recommended permissible values for these parameters of goodness of fit. As the ratio of chi-square to the degree of freedom (χ2/DF) less than 5 indicate a reasonable fit of SEM model (Marsh and Hocevar, 1985), GFI, AGFI, and CFI greater than .90 indicate good fit of model (Bentler and Bonett, 1980, Bentler, 1982), RMSEA less than .08 shows a good fit (MacCallum et al. 1996), RMR less than .08 is acceptable (Hu and Bentler, 1999). By comparing the estimated values with recommended ones, a model can be accepted or rejected, and if rejected, then alternative models can be tested that best fit to the hypothesis and collected data. These recommended values of parameters will be used in next chapters to check fitting of developed models in estimating the respondent's perceptions and attitudes.

3.4.5 **Limitations and Advantages of SEM**

The arrows directions in a SEM model represent the researcher's hypothesis of causality as shown in figure 3-8. Choices of variables and paths represented by researcher in the model limit the ability of SEM in creating the sample variance and co-variance patterns that have been observed in the nature. Due to this, there may be several models fit equally well to the given data. For SEM, all endogenous variables should be interval or ratio scale variables (in practice, ordinal level endogenous variables are accepted and procedures for interval and ratio level data in AMOS are robust when using ordinal level data with 4 or more categories in large samples). Despite of this, the SEM approach is handy for multivariate analysis.

The SEM model can handle a large number of endogenous and exogenous variables as well as latent variables specified as linear combinations of the observed variables (Golob, 2003). The SEM methodology has several advantages over older generation of multivariate procedures and has become a popular methodology for non-experimentally research, where methods for testing theories are not well developed and ethical considerations make experimental design unfeasible (Bentler, 1980). Main advantages are listed below:

- It's a confirmatory rather than an exploratory approach to the data analysis
- It has ability to test multiple hypothesis at one time with multiple dependents
- Easiness of use graphical modelling interface
- It provides flexibility in assumptions (allow interpretation of results even in the occurrence of multi-co linearity)
- It can incorporate both unobserved and observed variables
- It enables the estimation of bi-directional relationship between variables whereas regression allows only unidirectional relationship

- It can illustrate direct effects between variables and indirect effects through mediating variables, such as the influence of attitudes on travel behaviour
- It has ability to test coefficients across different groups (multi-group analysis)
- It has ability to handle difficult data and large number of variables
- It provides explicit estimate of error variance parameters
- It is more effective in distinguishing the performance of competing hypotheses
- It assumes ordinal scales and discrete choice variables as individual-specific terms that take advantage of repeated measurements to account for population heterogeneity.
- Allow joint estimation of revealed preference (RP) and stated preference (SP) data

3.4.6 **Factor Analysis**

It is a best-known statistical procedure for investigation of relationships between sets of observed and latent variables. In using this approach to data analysis, the researchers examine the covariance among a set of observed variables in order to gather information on their underlying latent constructs (i.e., factor). In general, the factor analytic model focuses solely on how, and the extent to which, the observed variables are linked to their underlying factors. Specifically, it is concerned with the extent to which observed variables are generated by the under lying latent constructs and thus strength of the regression paths from the factors to the observed variables (the factor loadings) are of primary interest. There are two basic types of factor analysis: exploratory factor analysis (EFA) and confirmatory factor analysis (CFA). EFA is designed for the situation where links between the observed and latent variables are unknown or uncertain. The analysis thus proceeds in an exploratory mode to determine how, and to what extent, the observed variables are linked to their underlying factors. Typically, the researchers wish to identify the minimal number of factors that account for co-variation among the observed variables. In contrast, CFA is appropriate to use when the researcher has some knowledge of the underlying latent variable structure (Byrne, 2010). Based on the knowledge of theory and empirical research, researcher postulated relations between the observed measures and the underlying factors and then tests this hypothesized structure statistically.

3.4.7 **Application of SEM in Transportation Research**

Various researchers in the field of transportation have applied the SEM methodology for evaluating the travel behaviour, perceptions to service quality of public transportation modes, road safety, diver's speeding behaviour, and acceptability of demand measures. In most of the studies, SEM was applied in dealing with latent variables that are traveller's attitudes, norms, beliefs, intention, behaviour, and preferences.

The earliest and well known applications are a joint model developed by Den Boon (1980) of vehicle ownership and usage, and a dynamic model of mode choice behaviour and user's attitudes (Lyon, 1981).

Simultaneous equation models of travel behaviour and attitudes by Tardiff (1976) and Dobson *et al.* (1978) that give a full-blown to SEM applications in travel behaviour. Tardiff (1976) used path analysis to show empirical evidence that the causal link from choice behaviour to attitudes is stronger than the link from attitudes to choice behaviour. Various studies using different pattern of simultaneous educational modelling show that attitudes are conditioned by choices, while at the same time, attitudes affects choices (Dobson *et al.* 1978). Using panel survey data for San Diego, California, models developed by Golob *et al.* (1997) which include factors such as changes in travel times, attitudes toward carpooling, mode choice, and use of an exclusive freeway lane for carpools.

Golob and Hensher (1998) employed SEM to address the dichotomy between an individual's behaviour and his or her support for policies that are promoted as benefiting the environment. Golob *et al.* (1997) combined SP and RP data in California to explain vehicle usage as a function of vehicle type, vintage, fuel type to predict use of limited range electric vehicles. Levine *et al.* (1999) present two latent variable models that explain financial support for public transport and support for an institutional reform in public transit planning. Jakobsson *et al.* (2000) used five latent variables to investigate causality among acceptance of road pricing, behavioural intention concerning reductions in car usage, and feelings related to fairness and infringement on personal freedom. Garling *et al.* (2001) explored decision making involving driving choices by using latent variables to test links among attitude towards driving, frequency of choice of driving, and revealed presence of a certain type of decision process. Golob (2001) tested a series of joint models of attitude and behaviour to explain how both mode choice and attitudes regarding a combined HOV and toll facility differ across the population.

Eriksson *et al.* (2006) explain the importance of problem awareness, personal norm, freedom, and fairness in the acceptability of TDM measures using SEM tools. Bamberg *et al.* (2007, 2011) evaluated the importance of soft policy measurers using application of structural equation modelling and joint framework of behavioural theories. Nordfjaern *et al.* (2010) evaluated the driver attitudes, personality variables, and behaviour in different geographical areas. Choocharukul *et al.* (2006) with the application of SEM explain the psychological determinants of people moral obligation of car use reduction and acceptance of car use restriction in Japan and Thailand. Okamura et al. (2011) apply the SEM tools and identify the importance of auto-oriented and transit oriented lifestyles in presences to use public transportation modes. Other application include: development of structure of user's satisfaction with urban public transport service (Githui *et al.* 2010), causal relationship regarding quality of service of public transport in Indonesian cities (Joewono *et al.* 2010, 2005)' evaluation of urban passenger transport structure (Zhang *et al.* 2005), driver's speeding behaviour using TPB (Warner and Aberg, 2006).

3.5 APPLICATION OF GENETIC ALGORITHM (GA)

GA is Artificial Intelligence (AI) methodology that stimulates the Darwin's evolution theory. The process of evolution involved in GA ensures the survival of the fittest. The principles of Genetic Algorithms (GAs) were initially conceived by John Holland in the 1960s. Ever since, Gas have received much attention from the scientific community. Unlike traditional optimization or search methods, GA examines a pool of probable solutions simultaneously, not just one. GA is well accepted for its simplicity of operation and power of effect (Goldberg 1989). No wonder, GAs have been employed in a wide variety of fields including aerospace engineering (Obayashi et al. 2000), astronomy and astrophysics (Charbonneau 1995), financial markets (Mahfoud and Mani 1996), geophysics (Sambridge and Gallagher 1993), material engineering (Giro et al. 2002), and the list continues.

Solution candidates in GAs are organized as chromosomes and form the search space known as population. Chromosomes compete for survival and cooperate to achieve a better adaptation (Cezary and St. Clair 1995). Driven by selection pressure and information inheritance, after a few generations of reproduction via crossover and mutation, the population finally reaches convergence—a situation where most of the population is identical, or simply, diversity is minimal. It is desirable to find optimum solutions in a converged stage.

3.5.1 3.5.1 Implementing GA – Genetic Operators

GA begins with the ***selection*** of population that contains possible set of solutions in the form of chromosomes. Solution so from one populations are selected based on their fitness value with the possibility that new population will be better than the old one. The process continues until it finds the best solutions as per the defined fitness function. To create a new population from the previous one special operators are applied crossover and mutation. The performance of algorithm mainly depends on these two most important operators; crossover and mutation.

Prior to initiate a genetic algorithm, a method is required to encode the possible solutions to make it understandable and process able for the computer. There are several ways of ***encoding***, however selection of a particular encoding method depends on the nature of problem to solve. Binary, value, permutation and tree encoding are the few examples of encoding methods used for GA. Among these, permutation encoding is used for ordering problem, where one has to find a sequence or a path. In this, each chromosome is a string of numbers that represents the position in a path. Travelling salesman problem and eight queens' problem are the examples of permutation encoded problems.

The first genetic operator selects the optimal solutions from the given population. The quality of the optimal solution lies in how close it is from the desired results. These selected solutions are further brought to have crossover and mutation. ***Crossover*** combines the two chromosomes to produce a new offspring. The new offspring takes the best properties from both of the parents and is expected to be better than both of the parents. It occurs at the user defined crossover probability value. One point, two point, uniform, heuristic are the examples of crossover. After crossover, ***mutation*** operator takes place. This operator is to ensure the genetic diversity in the offspring. It helps the algorithm from falling in any local optimum point and ensures that the solution is global minimum.

The pseudo code pf GA is given below;

Algorithm GA is

// start with an initial time t := 0;

// initialize a usually random population of individuals initpopulation P (t);

// evaluate fitness of all initial individuals of population evaluate P (t);

// test for termination criterion (time, fitness, etc.) while not done do // increase the time counter t := t + 1;

// select a sub-population for offspring production P' := select parents P (t);

// recombine the "genes" of selected parents recombine P' (t);

// perturb the mated population stochastically mutate P' (t);

// evaluate it's new fitness evaluate P' (t);

// select the survivors from actual fitness P := survive P,P' (t); od end GA.

3.5.2 Advantages of Genetic Systems

Genetic algorithms are an important problem solving technique. The genetic programming paradigm is a recent designation of a new class of genetic algorithm. The algorithm uses a strategy of a directed search through a problem state space from a variety of points in that space (Goldberg, 1989). For this reason, Davis, (1991) has identified three main advantages of the genetic algorithm in optimization:

"First, they generally find nearly global optima in complex spaces. This is important because the search spaces for our problems are highly multimodal, a property that leads hill-climbing algorithms to get stuck in local optima.

Second, genetic algorithms do not require any form of smoothness [i.e., the problem state space need not be continuous].

Third, considering their ability to find global optima, genetic algorithms are fast, especially when tuned to the domain on which they are operating" (Davis 1991).

Another advantage of genetic algorithms is their inherently parallel nature, i.e., the evaluation of individuals within a population can be conducted simultaneously, as in nature.

The greatest advantage of GAs over many traditional optimization methods is that Gas work with the population of points instead of a single point. Because there are more than one point being processed simultaneously, it increases the probability of obtaining global optimum solution even in ill-behaved function (Goldberg, 1989).

3.6 APPLICATION OF TRAVELLING SALESMAN PROBLEM (TSP)

The Traveling Salesman Problem (TSP) is one of the most widely studied combinatorial optimization problems. Its statement is deceptively simple, and yet it remains one of the most challenging problems in Operational Research. It was studied in the 18th century by a mathematician from Ireland named Sir William Rowam Hamilton and by the British mathematician named Thomas Penyngton Kirkman.

Definition: Given a set of cities and the cost of travel (or distance) between each possible pairs, the TSP, is to find the best possible way of visiting all the cities and returning to the starting point that minimize the travel cost (or travel distance).

Let G = (V, A) be a graph where V is a set of n vertices. A is a set of arcs or edges, and let C: (Cij) be a distance (or cost) matrix associated with A. The TSP consists of determining a minimum distance circuit passing through each vertex once and only once. Such a circuit is known as a tour or Hamiltonian circuit (or cycle).

There are several interpretation of TSP however the most common practical interpretation is that of a salesman seeking the shortest tour through n clients or cities. This basic problem underlies several vehicle routing applications, but in this case a number of side constraints usually come into play (Laporte, 1992). It is used in many application areas like planning, logistics, manufacturing of microchips, DNA sequencing, vehicle routing problems, robotics, airport flight scheduling, time and job scheduling of machines (Matai et.al. 2010).

Classification: Broadly, the TSP is classified as symmetric travelling salesman problem (STSP), asymmetric travelling salesman problem (ATSP), and multi travelling salesman problem (MTSP). This section presents description about these three widely studied TSP.

(i) STSP: In STSP the distance between two cities is same in both the directions that mean this will result in an undirected graph.

(ii) ATSP: In ATSP the distance between two cities is not same in both directions. It is a directed graph and distance is different in both the directions.

(iii) MTSP: The MTSP is defined as: In a given set of nodes, let there are m salesmen located at a single depot node. The remaining nodes (cities) that are to be visited are intermediate nodes. Then, the MTSP consists of finding tours for all m salesmen, who all start and end at the depot, such that each intermediate node is visited exactly once and the total cost of visiting all nodes is minimized. The cost metric can be defined in terms of distance, time, etc.

Possible variations of the problem are as follows: ***Single vs. multiple depots***: In the single depot, all salesmen finish their tours at a single point while in multiple depots the salesmen can either return to their initial depot or can return to any depot keeping the initial number of salesmen at each depot remains the same after the travel. Number of salesmen: The number of salesman in the problem can be fixed or a bounded variable. Cost: When the number of salesmen is not fixed, then each salesman usually has an associated fixed cost incurring whenever this salesman is used (Matari et.al. 2010). In this case, the minimizing the requirements of salesman also becomes an objective. Timeframe: Here, some nodes need to be visited in a particular time periods that are called time windows which is an extension of the MTSP, and referred as multiple traveling salesman problem with specified timeframe (MTSPTW). The application of MTSPTW can be very well seen in the aircraft scheduling problems. Other constraints: Constraints can be on the number of nodes each salesman can visits, maximum or minimum distance a salesman travels or any other constraints. The MTSP is generally treated as a relaxed vehicle routing problems (VRP) where there is no restrictions on capacity. Hence, the formulations and solution methods for the VRP are also equally valid and true for the MTSP if a large capacity is assigned to the salesmen (or vehicles). However, when there is a single salesman, then the MTSP reduces to the TSP (Bektas, 2006).

3.6.1 Solving TSP using Genetic Algorithm Approach

TSP is an optimization problem where optimization is the process of making something better. An optimization problem is a problem which boosts the solution or finds the better solution from all available solution spaces. The terminology “best” solution implies that there is more than one solution. The Travelling salesman problem also results in more than one solution, but the aim is to find the best solution in a reduced time and the performance is also increased. TSP has several local minima, and the target is to find the global minima instead. Application of GA for solving TSP maximizes the probability of finding global minima. Specific genetic operators prevent algorithm from stagnating at any local minimum point. Genetic algorithm optimizes the initial solution to produce better results for a problem.

The main focus of the travelling salesman problem is to find the shortest path to travel through the given cities and to minimize the cost. The genetic algorithm is applied to improve the solution for travelling salesman problem. For travelling salesman problem generating initial population means finding all possible tours for the problem. Each chromosome represents the path travelled by the traveler. Each gene in the chromosome represents the cities to be travelled. The length of the chromosome is always the total number of cities plus one.

3.7 SUMMARY

This chapter provides the detailed background of the study area. It mainly includes the current transportation network and modes of Lahore city. The details of city's Metro bus, Bus Rapid Transit system (BRTS), and current available feeders are also presented in this chapter. Further it provides the methodology of the research study and structure and locations of the questionnaire field surveys. The analysis and modelling techniques, used in the study area also described in this chapter.

Chapter 4
EVALUATION OF CURRENT TRAVEL PATTERN AND ACCESS CHARACTERISTICS

City's travel pattern plays a primary role in making transit based decisions and therefore should be carefully examined and analyzed before. The share of each available mode is an important component in developing sustainable transport within a city or region. In recent years, many cities have set modal share targets for balanced and sustainable transport modes. These goals reflect a desire for a **modal shift**, or a change between modes, and usually encompasses an increase in the proportion of trips made using sustainable modes. In order to assess the current modal share for feeder trips, this chapter presents the details of existing travel form of particularly those commuters, who make their trip using BRTS. It basically includes the feeder modes being used for the first (origin to BRTS station) and last part (BRTS station to destination) i.e. for access and egress purposes respectively. Based on the questionnaire surveys, firstly the modal share was analyzed, relationship between some socio economic features and travel pattern were examined.

4.1 RESPONDENTS' SOCIO ECONOMIC CHARACTERISTICS

For the research purpose two types of interview surveys were conducted as discussed in chapter 3. The major difference between these two, is the survey locations and then obviously respondents too. This section holds the primary details about respondents' socioeconomic characteristics, for both the surveys:

The ***first type of interview questionnaire survey*** was conducted at selected BRTS stations and so all the respondents are BRTS users, though the frequency of usage varies individually which was also inquired in the questionnaire. Among all the respondents, only 7% (22) females were interviewed. This is not only due to their relatively lesser travel activities particularly using any public transport, but also due to the reluctance or hesitation towards giving interview. More than 50% of the respondents revealed that they belong to low income group i.e. their monthly income level is less than 20,000 PKR. Almost 24% users were students owing to 0 income, this is obvious as BRTS corridor provides direct access to many colleges and institutes. However share of middle-higher income group commuters in nearly insignificant only 1.3% (4). Since most of the respondents belong to low income group therefore the rate of vehicle ownership is quite less among the users. A high percentage of users; 56% (175) own no vehicle, while 32% own only one motorcycle. It was found that most of the users having the trip purpose as 'work' around 66% (206) and then 'education', 18% (56). This is due to the location of BRTS corridor that targets many of the activity centers and hubs, making it feasible for workers to commute through it. Most of the users were found to be quite frequent and use BRTS on daily buses, 49% (153), however 27% (27) use at least once per week. Further details of socio economic characteristics are presented in Table 4.1.

For the ***second type of interview survey***, the locations were few offices, work places, shopping areas and institutes, located nearby the BRTS corridor and the respondents were the workers at these places, who commute daily. The purpose of this survey was to assess the travel pattern of those, who can make their egress part by walk to reach their destination, in other word whose workplaces are nearer/ within walking distance of given BRTS station. Among these respondents, Male was the significant gender, and only 1.4% (4) females were interviewed. This is due to the relatively lower percentage of working women overall, and then their reluctance towards interview. Low income and lower middle income class was found more being 63% (186) and 26% (78) respectively. However as per the interviewers' remarks, most of the respondents were little unwilling towards providing their income level information, and so might be the results were under/overestimated. Majority of the respondents own no vehicle, 49% (145), and among the rest Motorcycle ownership came out to be dominant. Respondents were also asked about their main travel mode, which they use daily to come to their work places, and the results showed that app. 44% (131) use BRTS as the main travel mode. Further details of respondents' socio economic characteristics are given in table 4.2.

4.1.1 Cross Tabulation of Socio Economic Characteristics

Firstly all the data from the two surveys, was analyzed for the socioeconomic characteristics, with the help of cross tabulation. For the first type of survey from users, a cross tabulation analysis was conducted for frequency of using BRTS and socio economic characteristics. Although all the respondents were definite BRTS users but survey results showed that they have varying degree of usage frequency, therefore there is need to identify the most frequent users' characteristics, in other words it is to analyze that frequent BRTS user own what kind of socio economic characteristics. Gender category was excluded from the analysis being insignificant. Other three features including: Income level, Vehicle ownership, and Trip purpose were cross tabulated against frequency of using BRTS. The results of cross tabulation are shown in Table 4.3. Based upon the results, firstly it is inferred that all the respondents irrespective of their frequency of using BRTS, have three significant characteristics:

i. Belong to Low income class
ii. Own No vehicle
iii. Have Work as trip purpose

These results point out that majority of BRTS users are transit 'captives', since transit captives have limited options other than to use transit or forgo desired travel. Also low income is a crucial determinant of low vehicle ownership that generates the captive behavior. Although the objective of BRTS is; to attract 'choice'

Table 4-1Socioeconomic Characteristics of BRTS users

Characteristics & categories	Percentage distribution (%)	Characteristics & categories	Percentage distribution (%)
Gender		**Frequency of using BRTS**	
Male	92.9	Daily	49.2
Female	7.1	Once per week	27.0
Income Level (PKR :Pakistani Rupees)		Rarely	23.8
0 / No income	24.1	**Trip purpose**	
Less than 20,000	54.7	Work	66.2
21,000 – 50,000	19.9	Education	18.0
51,000 – 100,000 or more	1.3	Shopping	4.5
Vehicle ownership		Entertainment	4.8
Bicycle	9	Other	6.4
Motorcycle	31.8	-	-
Car	2.9	-	-
No vehicle	56.3	-	-

riders and a mode shift, but it seems to be not achieved. However since the corridor passes through several work areas, therefore 'work' purpose was found dominant among the respondents. It was found that these characteristics are consistent for the respondents who use BRTS on daily basis. However chi-square test was performed to see the association of the three socio economic characteristics with frequency of using BRTS and results revealed a significant association or dependence for trip purpose. For which the size or measure of association was estimated by observing the value of Crammer's V which was 0.31 that shows a strong relation in between. ***Based upon this result it can be assessed that work commuters are the most frequent users, though most of these belong to low income class and so own no vehicle.***

For the second type of survey, all the socio economic characteristics were cross tabulated against, main travel mode used by the workers. A strong dependency was observed between choice of main travel mode and income level. The results dictate that low income group respondents were more prone to use the public transport including BRTS, local bus, and paratransit. However the trend of using private vehicle (motorcycle & car), was significant among lower middle and higher middle income classes. In addition to this, use of public transport is almost none among higher middle income class. Among respondents owing 0 income, use of 'other' as main travel mode was higher, since these were students and mostly used their corresponding institutes' pick and drop services.

The other socioeconomic characteristics, vehicle ownership was also cross tabulated against main mode of travel and the results showed significant association/ dependency in between. All the private vehicle owners (motorcycle and car) had strong tendency towards using private vehicle as their main mode of travel. Car

Table 4-2Socioeconomic Characteristics of Workers (Working Nearby BRTS Corridor)

Characteristics & categories	**Percentage distribution (%)**	**Characteristics & categories**	**Percentage distribution (%)**
Gender		**Main travel mode from origin to destination**	
Male	98.6	Walk	7.4
Female	1.4	Motorcycle	44.3
Income Level (PKR :Pakistani Rupees)		Local bus	8.8
0 / No income	8.1	Paratransit	19.3
Less than 20,000	62.8	Motorcycle	13.5
21,000 – 50,000	26.4	Car	5.1
51,000 – 100,000 or more	2.7	Other	1.7
Vehicle ownership		-	-
Bicycle	10.5	-	-
Motorcycle	33.4	-	-
Car	7.1	-	-
No vehicle	49.0	-	-

Table 4-3Cross Tabulation of Frequency of Using BRTS Vs Socio Economic Characteristics

Socio economic characteristics		Frequency of using BRTS		
		Daily	Once per week	Rarely
Income level	0 income	27.5%	20.2%	21.6%
	less than 20000	**50.3%**	61.9%	55.4%
	20000-50000	20.9%	16.7%	21.6%
	50000-100000	1.3%	1.2%	1.4%
Vehicle ownership	Bicycle	9.8%	11.9%	4.1%
	Motorcycle	28.1%	33.3%	37.8%
	Car	3.9%	0.0%	4.1%
	None	**58.2%**	54.8%	54.1%
Trip purpose	Work	**70.6%**	70.2%	52.7%
	Education	26.8%	9.5%	9.5%
	Shopping	0.0%	8.3%	9.5%
	Entertainment	0.7%	6.0%	12.2%
	Other	2.0%	6.0%	16.2%

owners were found to be more car oriented than that of motorcycle owners, therefore their share towards public transport was quite low. However each mode share for motorcycle owners was not trivial at all, though the usage of motorcycle was highest of all other modes. Whereas most of the public transport users owned no vehicle and few own motorcycle only, as per the survey results. It is also inferred that among the bicycle owners, mostly used 'other' as main travel mode. The details of analysis is presented in table 4.4.

Since the concept of income level and vehicle ownership are closely related to each other and go side by side, it can be concluded that public transport users mainly belong to low income class and own no vehicle. Moreover, lower and higher middle income group and private vehicle owners have strong tendency towards using their vehicle as main travel mode. Particularly for BRTS all the facts remain the same.

4.2 CURRENT MODAL SHARE

4.2.1 Feeders' Modal Share

In order to propose the design of feeder service for BRTS, it is conditional to examine the current feeder modal share and then evaluate these at certain levels. As per the available modes in the city, BRTS can be accessed by walk, public/local bus, paratransit or private vehicle, though the choice of certain feeder mode is absolutely affected by several other factors. Based upon the first type of field survey, a feeder modal share was developed to examine what modes are currently being used as feeders and what is the share of each one (Figure 4.1).

In any case, the prevailing feeder mode is Walk, and for egress phase share is even higher than that for access. Since the respondents were also asked about the distance (kms) covered during feeder phase, it was observed that most of the walk feeder trips are made for a distance of 0.5 to 1.00 km and among this the percentage of trips from 0.5 km is the highest. Almost 74% access and 82% egress walk feeder trips are

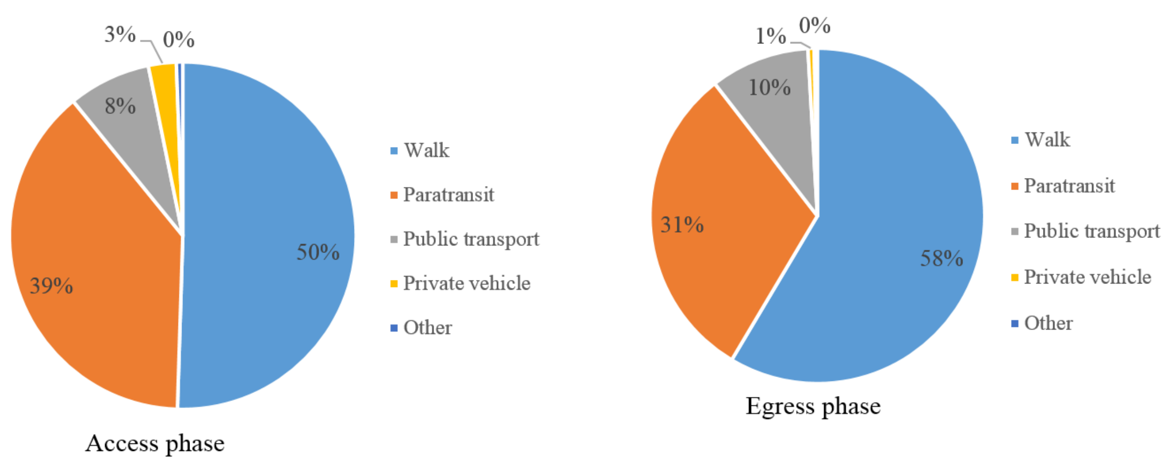


Figure 4.1Feeder Modal Share for Access and Egress Phases from BRTS

Table 4-4Cross tabulation of Travel mode choice vs Socio economic characteristics

Socio economic characteristic		Main travel mode from origin to destination (%)						
		Walk	BRTS	Local bus	Paratransit	Motorcycle	Car	Other
Income level	0 income	18.2	7.6	0.0	8.8	5.0	0.0	60.0
	less than 20000	**77.3**	**72.5**	**73.1**	**75.4**	25.0	0.0	40.0
	20000-50000	4.5	19.1	26.9	15.8	**67.5**	**60.0**	0.0
	50000-100000	0.0	0.8	0.0	0.0	2.5	**40.0**	0.0
Vehicle ownership	Bicycle	27.3	8.4	3.8	15.8	0.	0.0	80.0
	Motorcycle	18.2	27.5	42.3	21.1	**90.0**	0.0	0.0
	Car	0.0	3.1	3.8	0.0	5.0	**93.3**	0.0
	None	**54.5**	**61.1**	**50.0**	**63.2**	5.0	6.7	20.0

made within the distance of 1 km from BRTS station. This trend shows that use of walk as a feeder mode, is only made by those who live within 1.00 km from the nearest BRTS station. And as Walk has a lion's share among other modes, it highlights the fact that, majority of BRTS users are those who live/come and work/go nearby BRTS corridor.

In the modal share, the other significant feeder mode, after walk, is paratransit (Motorcycle rickshaws). The use of paratransit prevails for the distance of 1to 7 kms, for both access and egress phases. More than 70% trips are made for which the distance remained equal to or less than 7 kms, however percentage of trips from 2 km is highest. A certain percentage of trips is long distant ranging from 7 to 12 kms, whereas 90% trips are covered up to 10 kms.

Few feeder trips are also made by using Public transport, and it holds for local buses running in the city. The information about the distance for these feeder trips reveal that they are mostly used for longer distances. The distance of 4-5 kms is the most frequently used for, though the total range varies between 3 to 40kms. There are several factors that contribute towards their lower share, and will be discussed later (see chapter 5).

The use of private vehicle is quite insignificant, 3% for the access and only 1% for egress phase. All the access feeder trips, that were made using private vehicle, covered the distance between 2 to 7 kms.

A cross analysis was performed to perceive the overall travel pattern from origin to destination. The purpose is to find out if any relationship between one's choice of access and egress feeder mode, exists. The results show that overall walk is the most prevailing choice for egress part, irrespective of the mode opted for the access phase (Figure 4.2). However the commuters who use paratransit to access, are more inclined to use walk than any other mode. The results of cross analysis do not vary from that of modal share.

4.2.2 Commuters' main travel modes' Modal Share

For the second type of field survey, firstly a modal share was developed based on the main travel mode opted to reach their workplaces. The resulting modal share shows that BRTS is the most frequent mode choice made by the commuters, following paratransit and private vehicle (Figure 4.3). Although the share of BRTS is 45%, but it's higher than all. The share of paratransit and private vehicle (motorcycle and car) is found to be almost same, i.e. 20%. However the use of Local bus came out to be very low, lesser than that of even private vehicle. For walk being the main travel mode, share is only 7%, and it's only for those who have their workplaces nearer (within walking distance) from their residence.

After identifying the main travel mode, commuters using BRTS were separated for analyzing their further modal share for the feeder phase. The results showed that most of the commuters opt Paratransit to access the BRTS station and second mode is Walk. While for the egress phase Walk is the most significant almost 75%, commuters walk to reach their destination, and 24 % use paratransit (Figure 4.4). For the feeder trips by paratransit, 3 km is found to be the most frequently covered distance, however the range is 1 to 15 km.

Almost 80% trips have made from less than 8 kms and the trend remain same for access and egress phases. Whereas for walk 0.5 km is the most frequent walking distance within the range of 1 to 2.5 kms.

More than 80% of walk trips are generated from less than 1 km distance, for access and egress phases both. The closer examination of whole traveling, reveal that commuters who use walk to access are more prone to opt walking for the egress phase too. And those who go with paratransit, walking is significant mode for

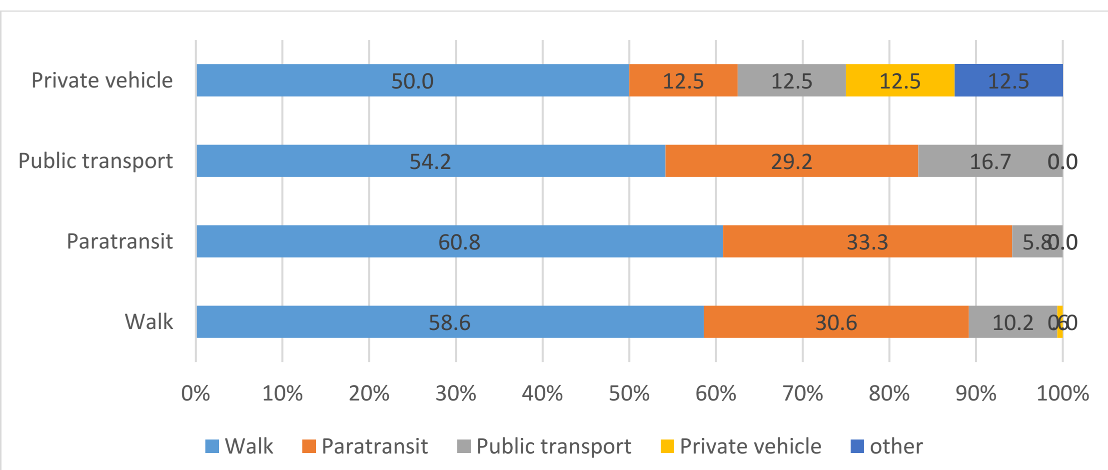


Figure 4.2Cross Analysis of Feeder Modes Opted For Access and Egress

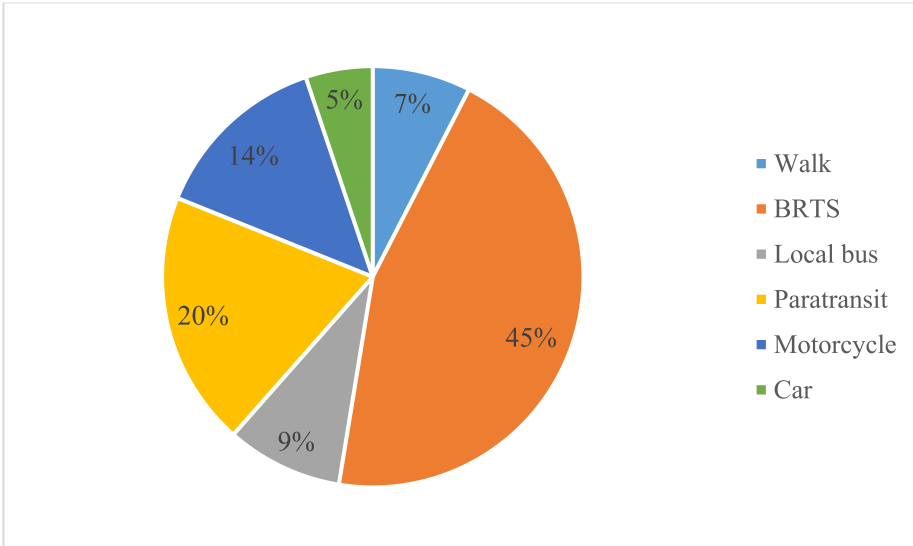


Figure 4.4 Commuters' Main Travel Modes' Modal Share

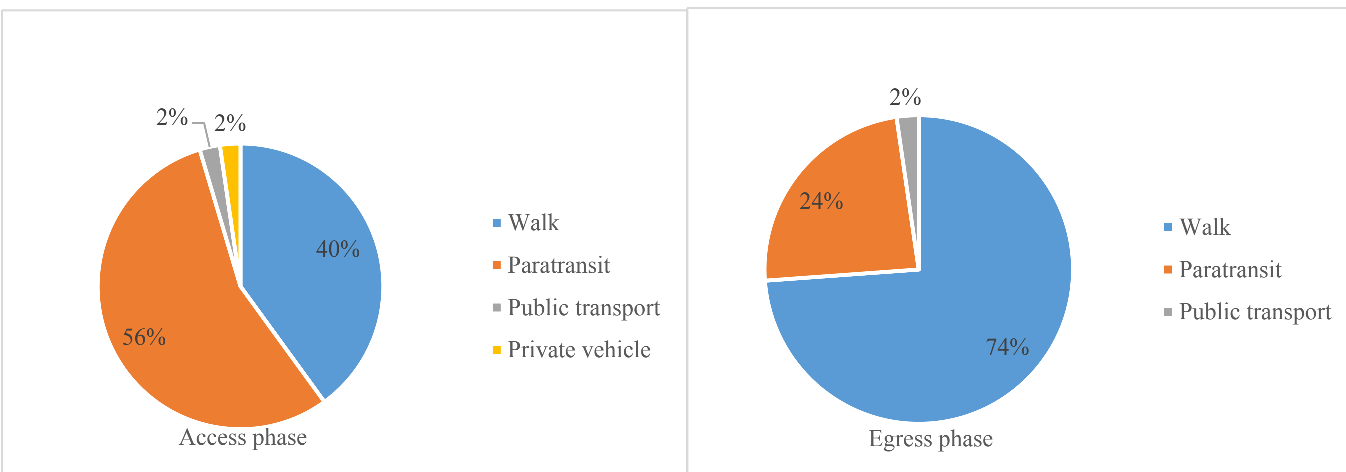


Figure 4.3 Commuters' Feeders' Modal Share

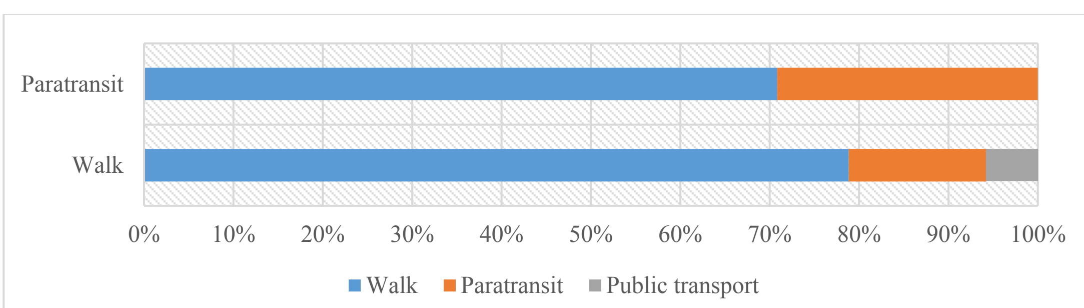


Figure 4.5 Feeders opted for access and corresponding feeders for egress

egress part too. But relatively share of paratransit is higher than for that of previous case (Figure 4.5). This may be the effect of one's own choice or few other factors like age, weather etc., however it's not studied here.

4.3 Summary

This chapter mainly describes field surveys' respondents' socio economic characteristics and their mode share for feeder purpose to access and egress from the BRTS stations. The results represent that majority of the BRTS users belong to low income group and own no vehicle. The most significant trip purpose among the commuters is found as 'work'. It is further observed that those who can walk to/from station are more likely to use the BRTS. Also, the survey at corridor's nearby activity centers reveal the major BRTS ridership of them, due to the nearness of their workplaces from the station, and hence can reach there by walk only. The proximity to station came out to be the most significant factor for using BRTS. The trend of using BRTS more by those who live or/and work at walking distances from the corridor is associated with certain facts, that will be discussed later in other chapters. In addition to walk, paratransit and public transport are the two modes for auto access/egress, used by the commuters. Among these two, the share of paratransit as feeder is higher than that of public transport.

Chapter 5
SPATIAL AND QUALITATIVE EVALUATION OF CURRENT FEEDERS

Based upon the results of modal share for the feeder phase, developed from the field surveys, two auto modes came out to be as current feeders: Paratransit and Public Transport. Although as per the survey results, the share of public transport as feeders, is significantly lesser, but these are the only regular services (on regular routes with certain stops) available overall in the city. And many officials claim that these buses are/can be using/used as feeders well, to access BRTS, therefore it is required to evaluate these too, along with paratransit, prior to propose any new feeder service. This chapter will address the evaluation details of each of these modes. For public transport, a GIS based spatial analysis is conducted as they have fixed stops (number and location) to find out the service area coverage of buses. Service area analysis is done for the public buses only, since these have the specified routes and stops. Furthermore to encompass the other aspects and evaluating the paratransit, few service quality attributes are selected, for which the respondents' perception is considered from the field surveys.

5.1 EFFECTIVENESS OF PUBLIC TRANSPORT

The effectiveness of public transport can be measured or evaluated in several ways. However the method of evaluation greatly affect the perceived value of the system. Among several approaches, the public transport coverage is the key point in making the system more user friendly and accessible to maximum people. Coverage is a measure of the proportion of a metropolitan area, corridor, or population served by transit (TCRP, 2004). Previously, for the study area, few researchers evaluated the public transport in terms of studying the general satisfaction of commuters towards public transport and the corresponding factors influencing their perception, but coverage area aspect of public transport is the ignored one. Whereas the presence or absence of transit stop near one's origin and destination is key factor in one's choice to use transit. When stop is not available, other aspects of public transit service do not matter for given trip (Vimal Gahlot, et.al. 2013)**.** Transit stop provided within a reasonable walking distance of one's origin and destination, enhances one's choice to use transit services in the nearby vicinity. Studies have shown that greatest predictor of transit use is proximity (Cervero, 2002; Gutierrez & Garcia-Palomares, 2008). The closer one lives to a transit stop, the more likely one will take transit (Hoehner et.al. , 2005). Bus stop coverage area is the area covered by a particular route within walking distance of transit stop (Figure 5.1).

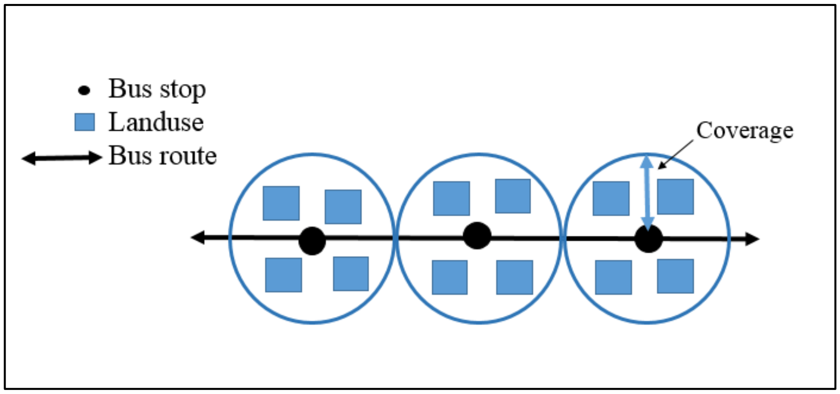


Figure 5.1 Concept of Coverage

The spatial location of the bus stop is sensitive to estimate the percentage commuters who can reach/access that bus stop by walk. Therefore service area or coverage analysis is the one way to measure the effectiveness of given public transport. As suggested by TCRP, 2004, a rule-of-thumb indicator of coverage is the presence or lack of transit service within 1/4 mile. For this research, 500 m distance is used instead, being notified as the most frequently used distance for walk trips according to the survey results.

5.1.1 GIS based Service Area Analysis

Lahore (the study area) has a network of public transport in the form of buses, running across the city. These buses travel on the defined routes and serve certain allocated stops. According to the sources, city has almost 56 bus routes, however the bus route map provided by the Lahore Transport Company (LTC), present only 30 planned bus routes, since most of the routes have become non-operational now (Figure 3.5). The route length and number of stop varies ranging from 15 km to 56 kms, though constant for each bus route. The operation of these buses is neither integrated with each other nor with BRTS. For measuring the service area, only those bus services/routes are considered that start/end/cross/move alongside for few miles, with the BRTS corridor, and hence can be used (as feeders). Based on this condition, 23 bus routes are identified that interact with the BRTS corridor in some way. A GIS based map is prepared to show the relative location of their respected stops with BRTS, presented in Figure 5.2. So if one is living within the service area of any of these stops, can use that bus service to reach BRTS station. Considering 500m, a walkable distance, a radial buffer is created around each of these stops including BRTS corridor (Figure 5.3). Overall walking environment is assumed to be favorable. The percent area inside the buffer or within 500m distance is then excluded to estimate the un-serviced area for each town (Figure 5.4). The distribution of population is non uniform within a town, that’s why percentage of unprivileged population is measured separately. For the measurement of privileged/unprivileged population, each town is sub divided into certain number of zones, for which the uniform population distribution is assumed.

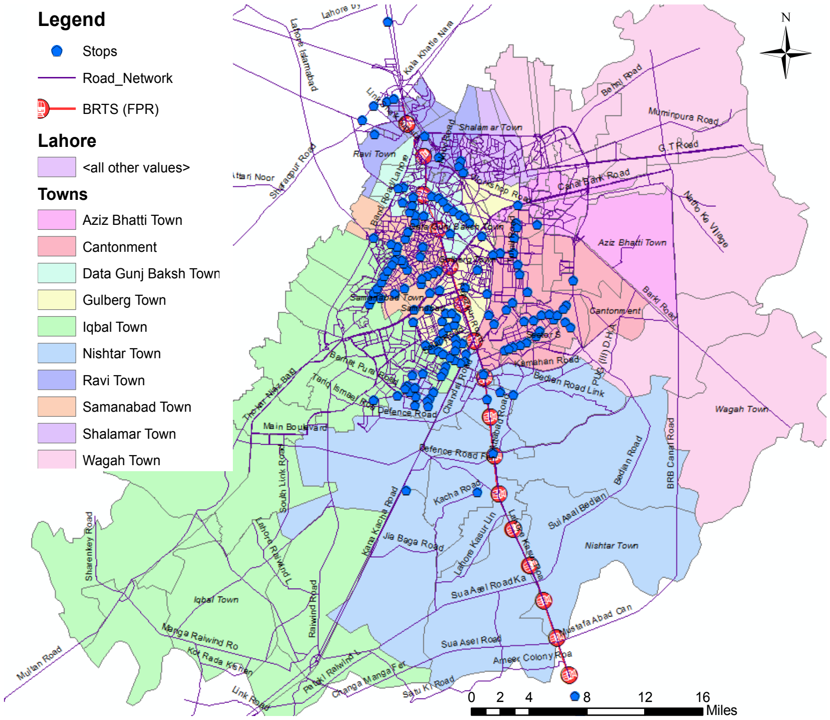


Figure 5.2 Location of Bus Stops Relative to BRTS

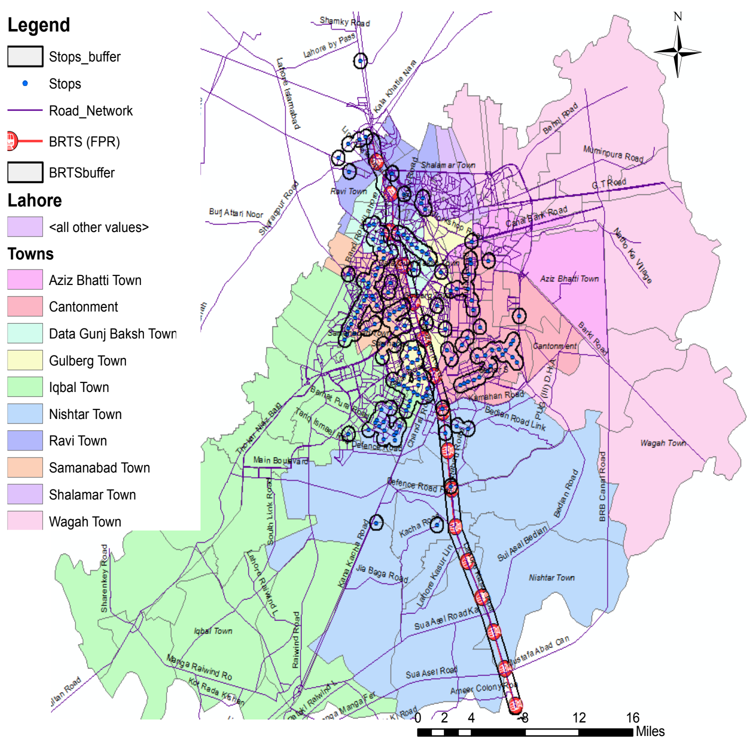


Figure 5.3 Placement of 500m Buffer Zone around Bus Stops & BRTS Corridor

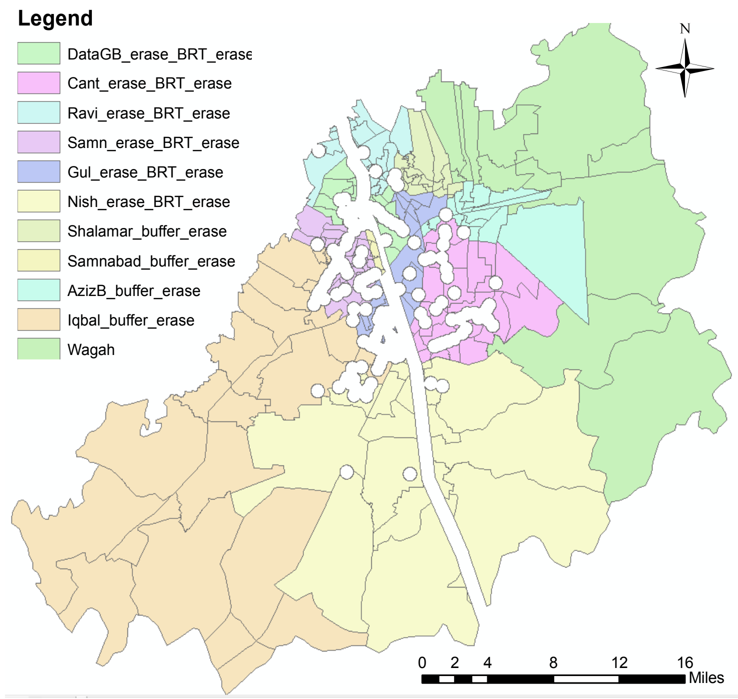


Figure 5.4 Spatial Analysis Map Excluding Service Areas

Discussion: The results of the spatial analysis, presented in Table 5.1, show that most of the residents of each town are not within the service area of any bus stop. The percentage of residents with access is far less for few towns like, Iqbal, Shalamar, and Aziz Bhatti whereas for Wagah it is even reduced to zero. However

since 80% of the city's population lives within 80 km from the city center, therefore Wagah and Iqbal towns can be waived off, being most of their parts far from the city center. Among rest of the towns, Data GB and Samanabad are the two, in which more than 50% of the population can access a bus stop and thus can use BRTS further. For other four towns the percentage of residents with access varies between 37 to 47 percent. By summing the results, overall 33% population can use BRTS either by using existing public transport (bus) as feeder or they live within walking distance from the nearby BRTS station.

These results clearly highlight the ineffectiveness of current public transport system in terms of coverage, and providing access to people. Also, the inference of 33% population with access, does not guarantee that they will surely use BRTS by taking existing buses as feeders. Since there are several other aspects of a public transport system, needs to be considered.

5.2 SERVICE QUALITY EVALUATION OF CURRENT FEEDERS BASED ON THE COMMUTERS' PERCEPTION

Another approach to evaluate the current feeders and proving their deficiency to be served as feeders is from the commuters' perception about these. Therefore service quality of current feeders is assessed based

Table 5-1 Percent Area &Population with/without Access

No.	Town	Percentage With Access (within 500m service area)		Percentage Without Access (outside 500m service area)	
		Area	Population	Area	Population
1	Aziz Bhatti	1.00	4.84	99.00	95.16
2	Cantonment	26.42	42.30	73.58	57.70
3	Data GB	51.10	58.15	48.90	41.85
4	Gulberg	47.78	47.28	52.22	52.72
5	Iqbal	2.22	19.44	97.78	80.56
6	Nishtar	7.45	37.74	92.55	62.26
7	Ravi	24.32	40.04	75.68	59.96
8	Samnabad	52.99	55.99	47.01	44.01
9	Shalamar	5.90	10.31	94.10	89.69
10	Wagah	0.00	0.00	100.00	100.00

on the commuters' perception for public transport and paratransit both, which was inquired during the field survey. For this purpose, six service quality attributes were selected empirically as discussed in chapter 3. The respondents are required to make their opinion on five point Likert scale against these attributes: Route reliability, Travel time, Travel cost, Comfort and convenience, Safety and security and Environmental aspects. Each attribute is selected carefully observing the current issues related to the conventional public transport and paratransit in the city.

5.2.1 Respondents' Socio-economic Characteristics

For the evaluation of commuters' perception, the data from the field survey type-I and II are combined, all those trips that are made by BRTS, using some kind of auto-access (paratransit, private vehicle, or public bus) as feeder, resulting in 379 samples. A significant majority of respondents is Male 93%. Almost 62% respondents belong to low income group whereas 61% own no vehicle. Most of the commuters have work as trip purpose. Among the feeder modes two modes are found in which share of paratransit is much higher than that of public transport. The detailed distribution of socio-economic characteristics are shown in Table 5.2.

5.2.2 Discussion on overall distribution of Perception

The results of the overall distribution of commuters' perception are presented in Figure 5.5. For ***route reliability*** about 43% of commuters consider it bad for paratransit, whereas for public transport lesser percentage of commuters perceived it as bad, 28%. Since here, route reliability means that a given service follows the set route and serve the defined stops. It is said that paratransit run on the specified route however actually they do not, also indicated from the survey results. Most of the times, they deviate from the main route sometimes to avoid congestion and sometimes to serve a certain area and this deviation is unknown to passengers and not fixed. As far as conventional public transport is concerned, mostly they follow the routes and serve the defined bus stops and hence more route reliable and less flexible. But even though these run on the designated route and stops, collecting and dispersing the passengers from any point, on their way, is quite common.

The term, ***travel time*** is generalized one that includes all the time losses, a commuter has to suffer from one's origin to the BRTS station. It can be expressed as;

Travel time = access time to reach the stop (of feeder) + waiting time for the given service (feeder) + in-vehicle travel time + access time to reach BRTS station

A higher percentage of commuters respondents (48%) perceives the travel time worse for public transport than that of paratransit (36%). As paratransit are lighter vehicles, move faster and more mobile than public transport which reduce the in-vehicle travel time. Also the operations of paratransit are more frequent, being more in number and they infiltrate to the residential streets and link roads where buses do not enter, therefore their access time and waiting time is better, about 33% respondents consider it good. Whereas the operation of conventional public transport is slower, due to; being often stuck in traffic jams and running with lesser speed than that of paratransit.

Both paratransit and public transport have varying ***travel cost*** (fare), roughly based on the distance. Most of the respondents show neutral opinion being 'Fair', towards this attribute; 69 and 68% for paratransit and public transport respectively. However paratransit has a little edge, due to having cheaper and negotiable fares. For public transport, fares are set by the transit agencies and a little higher.

Table 5-2Respondents' Socio-economic characteristics

Socio economic Category and distribution		% Distribution	Socio economic Category and distribution		% Distribution
Gender	Male	93.1	Trip purpose	Work	76.3
	Female	6.9		Education	13.2
Income level	Zero	17.9		Other	10.6
	Low	62.3	Feeder mode	Paratransit	84.2
	Middle low	18.7		Public transport	15.8
	Middle high	1.1	-	-	-
Vehicle ownership	Bicycle	5.3	-	-	-
	Motorcycle	31.7	-	-	-
	Car	1.6	-	-	-
	None	61.5	-	-	-

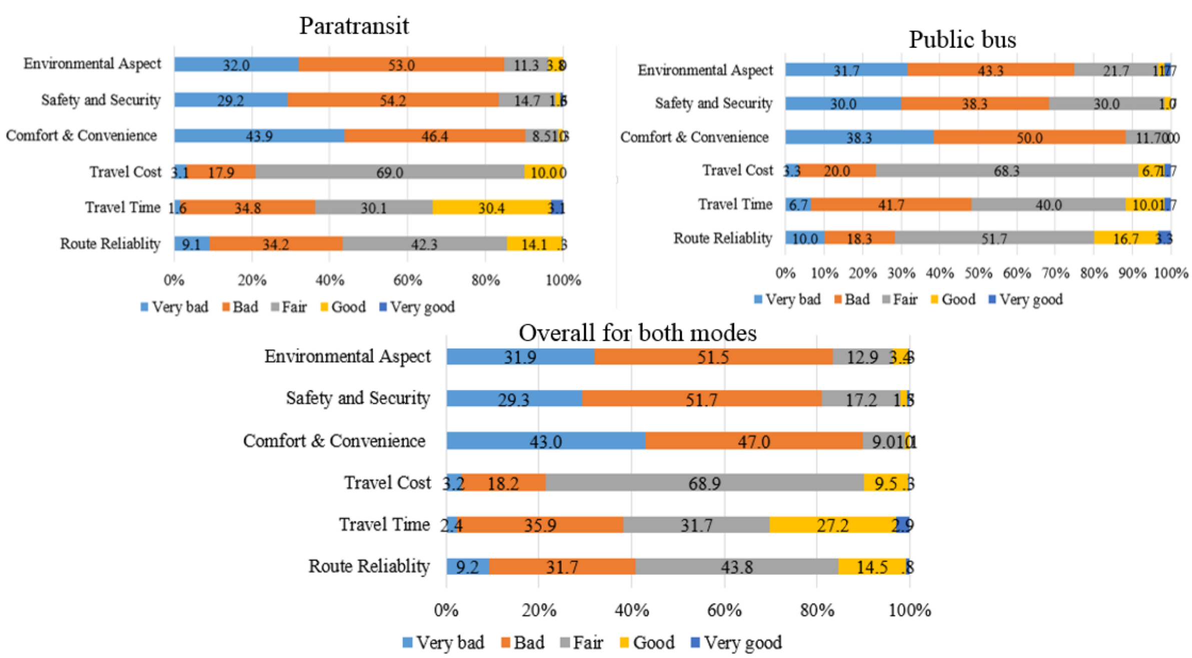


Figure 5.5 Commuters' perception for Service Quality Attributes

The attribute; ***comfort and convenience*** is related to the riding quality, seating and boarding/alighting comfort of the vehicle. Results show that majority of the commuters perceive this attribute the worst of all. For paratransit 90% and for public transport almost 88% mark it 'bad and very bad'. The results imply that both the modes are deficient in providing comfort and convenience to the passengers. These findings further validate the facts regarding paratransit service that they offer quite bumpy and uneven travelling with the rage driving.

The parameter; ***safety and security*** includes the perception of being, suffered from an accident and victim of a crime. Based on the commuters' perception, safety and security comes out to be another significant parameter that needs to be considered. For paratransit a relative larger percentage 83%, seems to be dissatisfied, however for public transport its 68%. This higher percentage of dissatisfaction from the commuters is due to the vehicle's physical aspects. The issue of vehicle's instability is often observed that causes accidents. Since the whole body is attached to a motorcycle therefore by loading more weight/passengers on rear side, vehicle often turn overs and so causes serious safety hazards.

Environmental aspects is the second largest dissatisfied attribute after comfort. It holds for the air and noise emission from the vehicle. 85% commuters perceive this as bad and very bad for paratransit while 75 % for public transport. Paratransit are also blamed for 80% city's pollution by the environmental department, due to not only the air pollution but the extreme noise, generated from their engine.

5.2.3 **Analyzing Perception – Factor Analysis**

The average response of commuters is measured as shown in Table 5.3. The lower average response indicates more negative evaluation of that attribute. As per the results, commuters seem to be relatively satisfied on monetary attributes like travel time and cost and also the operation of the service; route reliability. The attributes that are having most negative evaluation and so most dissatisfied by the users are more related to the riding comfort, safety and vehicular emission. Since the modal share results show that share of paratransit is much higher than that of public transport, the results can be more associated with the paratransit vehicle.

For further analysis, a factor analysis is conducted to find the latent factors among the observed variables. Factor analysis is used to uncover the latent structure (dimensions) of a set of variables. It reduces attribute space from a larger number of variables to a smaller number of factors. It attempts to explain the correlations between the observations in terms of the underlying factors, which are not directly observable.

Table 5-3 Average Response of Commuters to Service Attributes

Attribute	**Paratransit**	**Public transport**	**Overall**
Comfort &Convenience	1.67	1.73	1.68
Environmental Aspects	1.87	1.98	1.89
Safety & Security	1.90	2.03	1.92
Route Reliability	2.62	2.85	2.66
Travel Cost (fare)	2.86	2.83	2.85
Travel Time	2.99	2.58	2.92

The observed variables are the commuters' perception against the six attributes. The examination of the Kaiser-Mayer-Olkin, measure of sampling adequacy suggested that the sample is factorable. The reliability of the data is also within acceptable range, as measured from the Cronbach's Alpha.

The results of the rotated solution are shown in Table 5.4. When loading less than 0.50 are excluded, the analysis yielded a two-factor solution with the simple structure (factor loading $\geq$ 0.50). As per the factor analysis results, three items are loaded onto Factor 1.

These items are related to riding & seating comfort, ease of alighting and boarding, chances of being suffered from an accident and vehicular noise and air emission. These attributes can be fairly linked up with the structure of the vehicle and its physical aspects; vehicle which is being used as feeder and therefore labelled as '**Perception about Vehicle Based Aspects**' (VBA).

The other three items are loaded onto Factor 2. These three items are related to monetary attributes and operation of the feeders i.e. reliability. This factor loads onto commuters' reported perception about total travel time from origin to BRTS station, service fare and route reliability. The travel time can also be taken as the cost of travel, therefore this factor is labelled as **'Perception about Cost and Reliability'** (CR).

These two latent factors, accompanying with some other observed variables, are further used in analysis to signify the need of regular feeder service by bus or shuttle (see chapter 6).

Table 5-4 Rotated Factor Loadings for Service Attributes

Observed Variables	Component	
	1	2
Route Reliability		.649
Travel Time		.824
Travel Cost/ fare		.926
Comfort & Convenience	.852	
Safety & Security	.735	
Environmental Aspects	.842	
Eigen Value	2.834	1.510
Kaiser-Mayer-Olkin measure of sampling adequacy	0.694	
Cronbach's Alpha (α)	0.775	

Note: All the correlations were significant at 1%

5.3 Summary

This chapter evaluates the two feeder modes running in the city, conventional public transport and paratransit, in following two ways: Firstly, the conventional public transport is evaluated on the basis of geographical coverage. For this purpose, only those bus routes are selected that can lead one to the BRTS station. A service area analysis is performed by assuming that 500m is walkable distance, to find out the percent area and population with and without access. Results show that larger percentage of population is not living within service area of any bus stop and so are unprivileged. Only 33% population falls within 500m distance of a given stop. These result clearly indicate the poor spatial coverage of conventional public transport. The other approach to evaluate these feeders is based on the commuters' perception. For this purpose six (6) service quality attributes are selected empirically, against which commuters responses are measured and later on evaluated. The average response of the commuters indicate more negative evaluation of attributes related to comfort, safety and environmental aspects than others. These inferences imply that a comfortable, safer and environment friendly feeder service is more in demand than a cheaper one. Further a factor analysis is conducted to find out the latent variables between the observed variables of attributes. The results of factor analysis load these six attributes on two latent factors. These latent variables/factors are labelled according to the nature of the attributes; perception about cost and reliability and perception about vehicle based aspects. These two latent variables are further analyzed in the subsequent chapter.

Chapter 6
APPLICATION OF STRUCTURE EQUATION MODELLING TO SIGNIFY THE POTENTIAL OF REGULAR FEEDER SERVICE BY BUS/SHUTTLE

This chapter presents the application of structural equation modelling to highlight the significance of a new regular feeder service in the form of bus/shuttle. The analyses is based on the factor analysis results, performed in the preceding chapter. The influence of extracted factors along with other observed variables, over the BRTS accessibility is modelled using AMOS application. Additionally the potential of a better feeder service in future is evaluated by incorporating it with the commuters' willingness to pay for better feeder.

6.1 INFLUENCE OF COMMUTERS' PERCEPTION ON THE BRTS ACCESSIBILITY

The quality of the current feeder service is evaluated by modelling the BRTS accessibility under the influence of extracted factors, from the factor analysis, performed in chapter 5. The technique of factor analysis was used to uncover the latent structure (dimensions) and thus reducing the attribute space from a larger number of variables to a smaller number of factors. Two latent factors are identified; Vehicle Based Deficits (VBD), and Cost & Reliability Deficits (C&RD). For the vehicle based aspects, the variables are mainly associated with the hardware of the vehicle, being used, whereas for cost and reliability the variables are more fiscal oriented and related to the service reliability, and therefore named accordingly. In first step a measurement model is constructed, for which the attributes of feeder are the observed variables. The results of the model show that the standardized regression weights for all the observed variables are positive and significant at 1% (Figure 6.1).

6.1.1 Discussion on Model Results

The perception of commuters regarding environmental aspects and comfort have higher influence on vehicle based deficits. Similarly route reliability is weighted more than travel time and cost. This means that these are relatively influential factors and contribute more towards deprivation of current feeder service. The indices of goodness of fit parameters are lying within the permissible range i.e. chi-sq/DF < 5.0, RMR < 0.05, GFI, AGFI & CFI >0.90 and RMSEA < 0.08, which indicates that the given model has good fit in predicting the commuters' perception regarding deficiency or malfunctioning of current feeder service . This measurement model is further used in assessing the influence of current feeder's deficits over the BRTS accessibility. It is used to construct a structural model showing, commuters' perception affecting

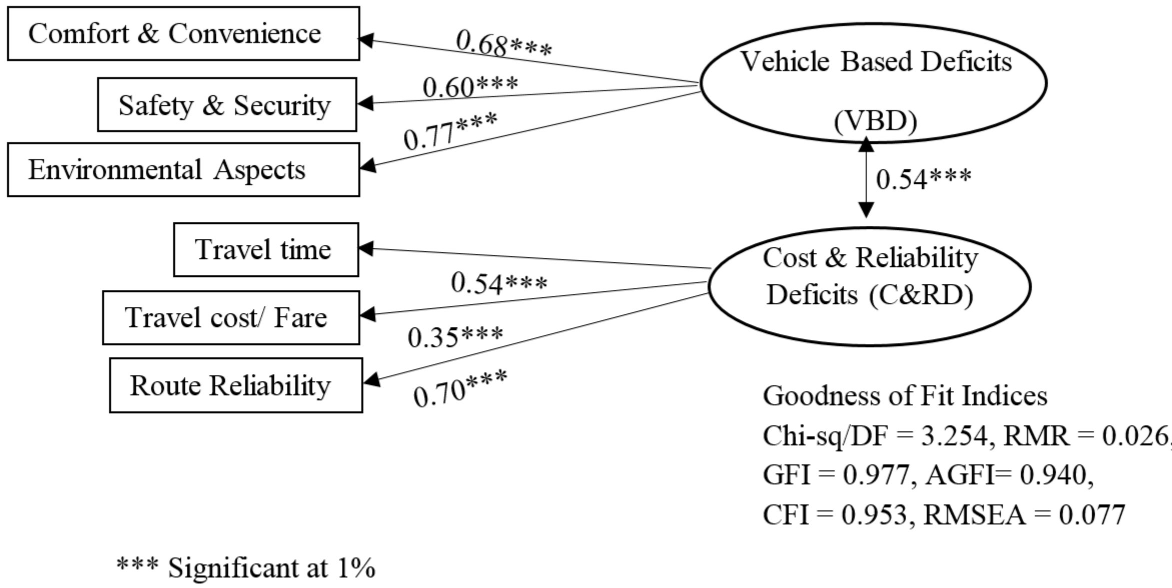


Figure 6.1 Measurement Model of Commuters' Perception for Feeders

BRTS accessibility. This structural model, is presented in Figure 6.2 and results of SEM are shown in Table 6.1. In this model, it is further hypothesized that feeder mode choice (paratransit), cost incurred (≤ 15PKR)and distance covered by feeder (≤ 5kms) are also the indicators of BRTS accessibility, therefore used as observed variables in the form of dummies.

These variables have positive impacts on accessibility which implies that more use of paratransit, incurring lesser cost and from lesser distance enhances the accessibility. According to the relationship between the latent constructs, cost and reliability deficits have positive influence, only significant at 90% level of confidence, whereas vehicle based deficits have negative influence on the accessibility and statistically insignificant. The positive influence of cost and reliability implies that these factors are relatively enhancing

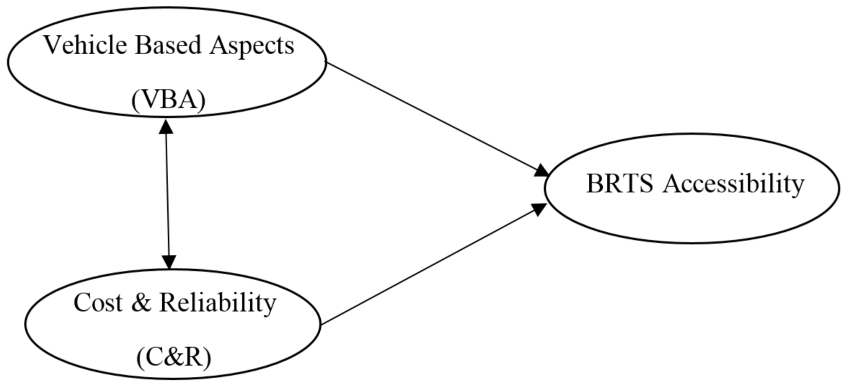


Figure 6.2 A typical structure of BRTS Accessibility based on Commuters' Perception

Table 6-1 Standardized Estimates of Structural Equation for BRTS accessibility

Structural Relationships	**Standardized Regression weights**
BRTS_Accessibility <------- VBA	- 0.056*
BRTS_Accessibility <------- C&R	0.245**
Environmental_Aspects <------- VBA	0.777***
Safety_Security <------- VBA	0.599***
Comfort_Convenience <------- VBA	0.682***
Route_Reliability <------- C&R	0.643***
Travel_Cost <------- C&R	0.377***
Travel_Time <------- C&R	0.580***
Paratransit_use <---- BRTS_Accessibility	0.403***
Cost_incuured <---- BRTS_Accessibility	0.459***
Distance_covered<----BRTS_Accessibility	0.677***
VBA <------> C&R	0.528***
Goodness of Fit Indices	
Chi-square/DF	3.206
RMR	0.027
GFI	0.956
AGFI	0.917
CFI	0.892
RMSEA	0.076

*** Significant at 5%, ** Significant at 10%, * p = 0.602

the BRTS accessibility, though with only 90% confidence. It infers that commuters are more satisfied by these aspects and so have positive perception. On the other hand, the negative impact of vehicle based aspects on current BRTS accessibility signify the issues related to the feeder's hardware.

It means that commuters are most dissatisfied by the factors that are linked with the physical condition of the feeder vehicle which is paratransit (motorcycle rickshaw). Being this relationship statistically insignificant implies that, commuters have much lower willingness to go with the current vehicle based deficits as these are, than cost and reliability.

All other relationships and co-relationships are significant at 5 % of level of significance. Based upon these results, it is argued that although the use of paratransit enhances the accessibility but factors associated with the vehicle dynamics degrades the feeders 'quality and therefore, in order to improve the BRTS accessibility, these aspects must be modified.

6.2 INFLUENCE OF CURRENT BRTS ACCESSIBILITY ON POTENTIAL OF NEW FEEDER BUS

The next step is to evaluate the potential of a better feeder service, other than paratransit in future. For this purpose, BRTS accessibility along with VBD and C&RD are used as exogenous variables, whereas 'willingness to pay for better feeder service', feeder mode and feeding distance; are used as dummy variables. Under the categories of feeder mode and distance, only 'paratransit' and 'distance ≤ 5km are considered, being significant than rest of the categories. A new endogenous latent variable is introduced and named as 'potential of regular feeder by bus/ shuttle' (Figure 6.3).

6.2.1 Discussion

The results of the model indicate that willingness to pay has significant positive influence on the potential of regular feeder service in the form of small bus/ shuttle in future. It implies that commuter's willingness to pay reveal the ultimate goal of initiating a regular bus feeder. Moreover feeder trips made from ≤ 5km distance also have a positive significant relation that shows that a regular feeder service will have tendency to increase the feeder trips, and subsequently BRTS ridership. The influence of cost and reliability is also positive but with the confidence interval of 90 %, since commuters seem to be more satisfied by these factors. On the other hand vehicle based deficits and overall current BRTS accessibility have not significant influence as commuters have much lesser tendency to go or consent with these aspects. The use of paratransit as feeder mode came out to be insignificant when linked with the potential for regular small bus/shuttle feeder, which shows the urge of providing a regular feeder service is not affected by the current usage of paratransit. The indices of goodness of fit parameters, as shown in table 6.2, are lying within permissible limits i.e. $\chi^2/DF < 5.0$, GFI and CFI > 0.90, AGFI ≈ 0.90, RMR < 0.05 and RMSEA < 0.08, which show that this model has reasonable good fit.

Table 6-2Standardized Regression Estimates for Potential of Feeder by Bus

Structural Relationships	**Standardized Regression weights**
Potential_BusFeeder <------- VBD	0.656 (p = 0.237)
Potential_BusFeeder <------- C&RD	3.665**
Potential_BusFeeder <---- BRTS_Accessibility	0.280 (p = 0.127)
WTP <------- Potential_BusFeeder	0.034***
Feeder_mode <------- Potential_BusFeeder	0.002 (p = 0.880)
Feeding distance <------- Potential_BusFeeder	0.063**
Goodness of Fit Indices	
Chi-square/DF	2.440
RMR	0.020
GFI	0.966
AGFI	0.932
CFI	0.921
RMSEA	0.062

*** Significant at 5%, ** Significant at 10%

Based on the model results, it is assessed that currently BRTS accessibility is significantly affected as per the commuters' perception regarding feeder which is paratransit.

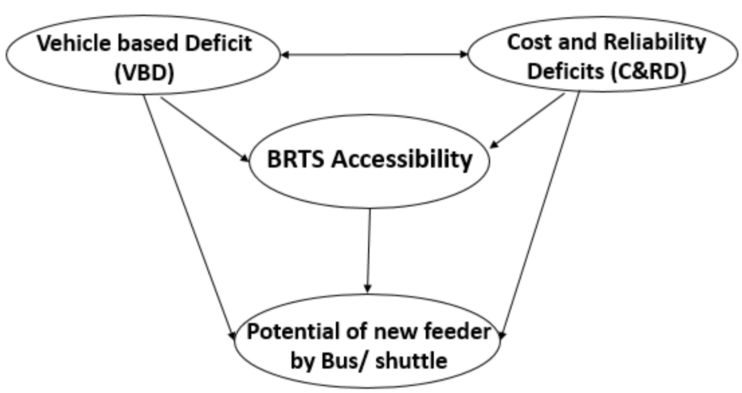


Figure 6.3 Structure of Finding the Potential Of Better Feeder Service

The deficits in the current feeders which are related to the hardware of the feeder vehicle i.e. comfort and convenience, safety and vehicular emission are more dissatisfied by the users.

These results seem to be very obvious, when it comes to paratransit which is a feeder vehicle. Currently the paratransit is comprised of motorcycle rickshaw that offers quite bumpy, uneven and harsh traveling experience.

The factor related to environmental aspects which is vehicular emission has highest positive influence on vehicle based deficits. This vehicular emission is more related to noise pollution due to the severe pricking noise produced from the engine. This is one of the reason that these paratransit are banned in some posh areas. Second comes the comfort and convenience offered by these vehicle which is mainly due to the uneven and bumpy riding quality. Conversely, commuters perceive travel cost (or time) offered by these paratransit, relatively better and so have lesser impact. The influence of route reliability is also notable, since most of these feeders follow and run based upon the driver's will, and do not have a regular route and stops. The influence of these factors on BRTS accessibility indicate that vehicle based deficits have negative impact and commuters assign very low scores for theses aspects. However the influence of cost and reliability deficits is still positive and so boosting the accessibility. Based upon these results it is inferred that although the current feeder service offers a cheaper and speedy mode, but commuters' perception regarding vehicle based deficits and reliability must be addressed in order to improve the BRTS accessibility. A comfortable, convenient, safer, environment friendly and reliable feeder service is more in demand. It is observed that these deficits are mainly due to the vehicle which is being used, since it is incapable of providing these facilities. Therefore it is identified that there is a strong and valid reason of providing a regular feeder service that mainly deals with the change of vehicle, a small bus or shuttle rather than the old motorcycle rickshaw.

Considering the change of vehicle and replacing it with small bus, commuters show strong willingness to pay for the service. The deficiency of current feeder mode due to the vehicular aspects, reliability issues and commuters' willingness to pay endorse the potential of better regular feeder service in the form of small bus/shuttle.

6.3 SUMMARY

This chapter exposes the harsh realities associated with the current feeder mode. It shows that paratransit which is the feeder mode, has enormous deficits in terms of comfort, convenience, safety and reliability. The results of the analysis reveal that BRTS accessibility can be improved by substituting the feeder mode with a small bus/shuttle which will provide passenger's comfort & convenience, their safety and be environment friendly also. Further there is a need to make this service regular to achieve the service reliability which is currently not present. Commuters' willingness to pay has major positive influence over the potential of regular feeder bus in future.

Chapter 7
SELECTION STRATEGIES FOR POTENTIAL DEMAND AREAS FOR FEEDER

This chapter presents the detailed methodology for laying out the feeder network, in perspective of the study area. Since the study area, Lahore has unique characteristics and limitations, likewise all other developing countries, this chapter encompasses all these aspects in a practical and realistic way. The methodology proposed for the feeder network design, addresses the actual issues, encountered particularly in developing urban structures in terms of routing the service, available right of way, stop area selection etc. Additionally, based on the methodology proposed, and utilizing the available data, few potential feeder routes are identified and plotted in certain areas.

7.1 SELECTION STRATEGIES

The design of a regular feeder service in the form of small/low capacity bus/shuttle that serves as a reliable, safer, comfortable and environmental friendly feeder mode for BRTS, requires vital considerations. Based on the previous results, current feeder vehicle must be replaced by some shuttle service and should be reliable. However to initiate, such feeder shuttle service that enhances the BRTS accessibility and thus attracts commuters who live/work beyond walking distance from BRTS, involves vigilant planning. In the subsequent sections, a step by step approach is described for the introduction of feeder service:

7.1.1 Potential Feeder Areas Based On the Land Use Factor

In order to initiate a feeder service for BRTS, it is utmost important to identify the areas that have potential demand for feeders. The areas that are served by these feeders must be highly feasible. Therefore this section provides the bases of selecting few areas over others. Among various factors, land use factors impact the travel activates significantly. Particularly distribution of land use activities within an area can substantially not only affect the decision of routing a service but also the decision of whether to start a service or not. Therefore few land use factors are considered for this purpose, among which density has major share, since the concept of density is connected with other landuse factors. In literature, the term 'compact development' is often found that includes other associated land use attributes along with density, instead of density. The increased population density tends to increase the traffic frictions, resulting in higher driving costs subsequently increase the use of public transit services and other options. Also density is often associated with other urban land use features such as regional accessibility, land use mix, connectivity, traffic speed control, and more diverse transport systems, which reduce driving and increase use of alternative modes (Litman, 2014). However in this study, Land use pattern of study area, Lahore is evaluated based on the attributes of land use type (mix) and population density and connectivity. These land use attributes are evaluated at 'Town' level to reveal the most preferred towns to be served by the feeders. For this purpose, secondary data, from Lahore Urban Transport Master Plan (LUTMP) which was prepared by JICA in 2010-11, is used.

Lahore city is divided into nine (9) towns, with administrative divisions (union councils) and one cantonment area, as shown in the Figure 7.1. Each town offers a mix of various land use types including mainly residential, commercial and educational. Firstly the major land use type of each town is identified based on their trip generation/ attraction statistics as provided by master plan study (LUTMP 2010-11).

1) Identifying Land use Type (mix) based on the Transport Demand; The very first consideration, towards selecting towns to be served by the feeders on priority bases, is 'the town should be more residential'. Primarily there are two logics behind;

1) BRTS corridor provides direct access to most of the workplaces, being located in Central Business District (CBD), and therefore requirement of a regular feeder that can shift commuters from their origin (residence) to nearby BRTS station, is more obvious. Also the proximity of workplace location to the BRTS station was found an influential factors in making transit trip. (Chapter 3) (Friedman et al., 1994; Handy, 1996a, b; Kitamura et al., 1997; Cervero and Gorham, 1995; Cervero and Radisch, 1996).

2) Travelling a larger distance to/from BRTS station at both the ends is assumed to be less feasible and attractive for the commuters as it will result in overall longer and costly trip. Also Chidambara (2010) showed that commuters want to keep the cost/time of the overall journey down and so are not willing to travel a larger distance to/ from the transit stops at both ends of the commute.

Landuse type information for a particular town is helpful in identifying the areas that can generate sufficient ridership for feeders. Not only this, this information is directly useful to classify 'to' and 'from' or 'access' and 'egress' trips during different times of a day. A residential landuse type will generate more work / to trips in the morning while more from trips in the evening, such inferences are beneficial for scheduling purposes also. landuse In order to proceed, based on the Lahore master plan, four types of trip based on the purpose, are reported from each town; to work, to school, private, business and to home as shown in Table7.1. These purpose-based transport demand statistics greatly assist in identifying the land use type of each town. A deep insight of the given figures reveal that Data GB and Gulberg attract a greater number of 'to work' and 'to school' trips than for the same purpose generated from the area (Figure 7.2).

Whereas Shalamar, Samanabad, Aziz B, Wagah and Nishter offer more homogenous land use in the form of typical residential towns where more 'to work' trips are generated than attracted. The other remaining towns; Ravi, Iqbal and Cantt have more or less similar proportion for generation and attraction

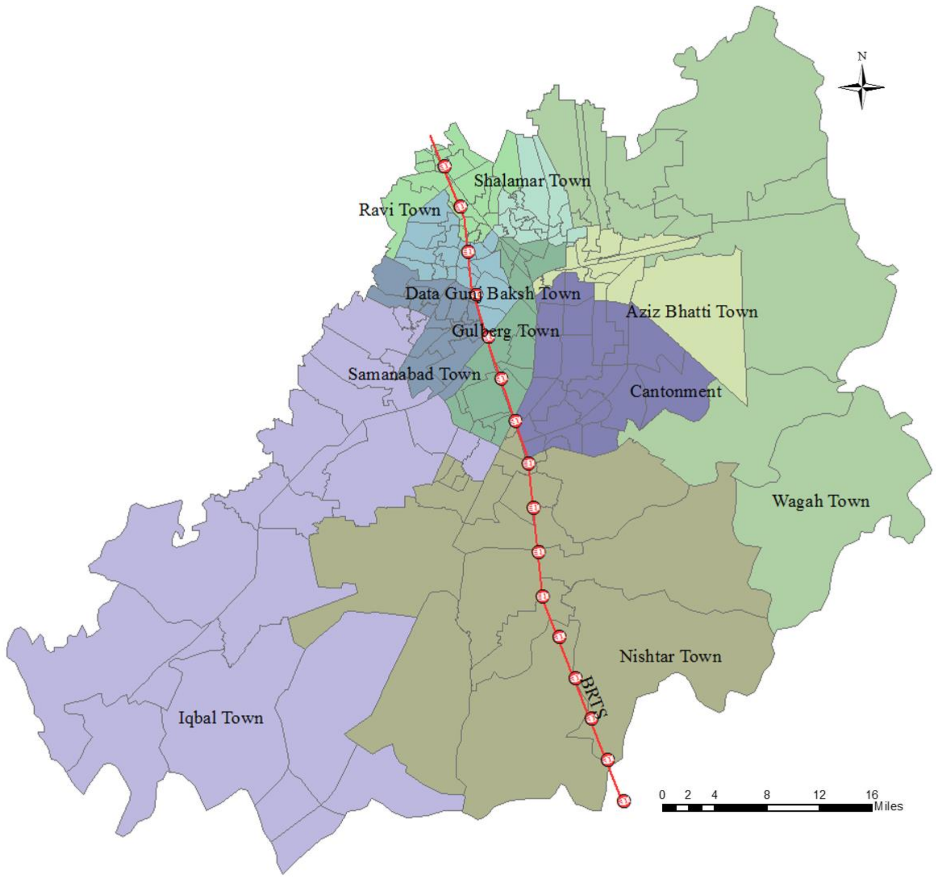


Figure 7.1 Administrative Towns of Lahore

for all trips, which indicate that these towns offer a relatively better mix of residential, educational and commercial/industrial (workplaces) land uses. The distribution of selected land uses types is presented in Figure 7.3.According to the first consideration of residential land use type; Shalamar, Samanabad, Aziz B, Wagah and Nishter towns can be considered, however Ravi, Iqbal and Cantt should not be overlooked at all. These selected towns also need to be evaluated from density point of view which is described in the subsequent section.

2) Population/ Density Breakdown to Study Area Towns; Higher population density tend to enhance the use of alternating modes than the private vehicle. The denser areas substantially improves the cost efficiency of sidewalks and public transit services. Also the per capita cost of providing transit services declines with density (Litman, 2014). These facts indicate that areas with higher density should be considered on priority bases than others.

As per the master plan study, the population of study area; Lahore is around 8.65 million that is almost evenly distributed in the towns excepting few peripheral towns like Aziz B, Wagah and Nishter Towns. Key study area population statistics are summarized in Table 7.2. According to these facts, the population

Table 7-1 Trip Generation/ Attraction by Town

No.	Town	Generations ('000/day)					Attraction ('000/day)				
		To Work	To School	Private	Business	To Home	To Work	To School	Private	Business	To Home
1	Ravi	226	92	39	21	426	272	72	62	38	336
2	DataGB	161	122	52	16	771	453	248	92	34	308
3	Samanabad	218	137	85	35	405	170	172	66	31	422
4	Shalamar	295	130	44	16	208	102	91	25	13	470
5	Gulberg	214	155	71	25	713	381	238	90	32	425
6	AzizB	188	124	41	14	189	88	62	31	9	360
7	Wagah	129	81	37	6	157	80	48	32	5	239
8	Nishter	179	70	41	16	204	126	41	34	8	312
9	Iqbal	207	135	79	24	424	262	135	82	25	379
10	Cantt	182	132	49	26	369	194	122	63	14	374

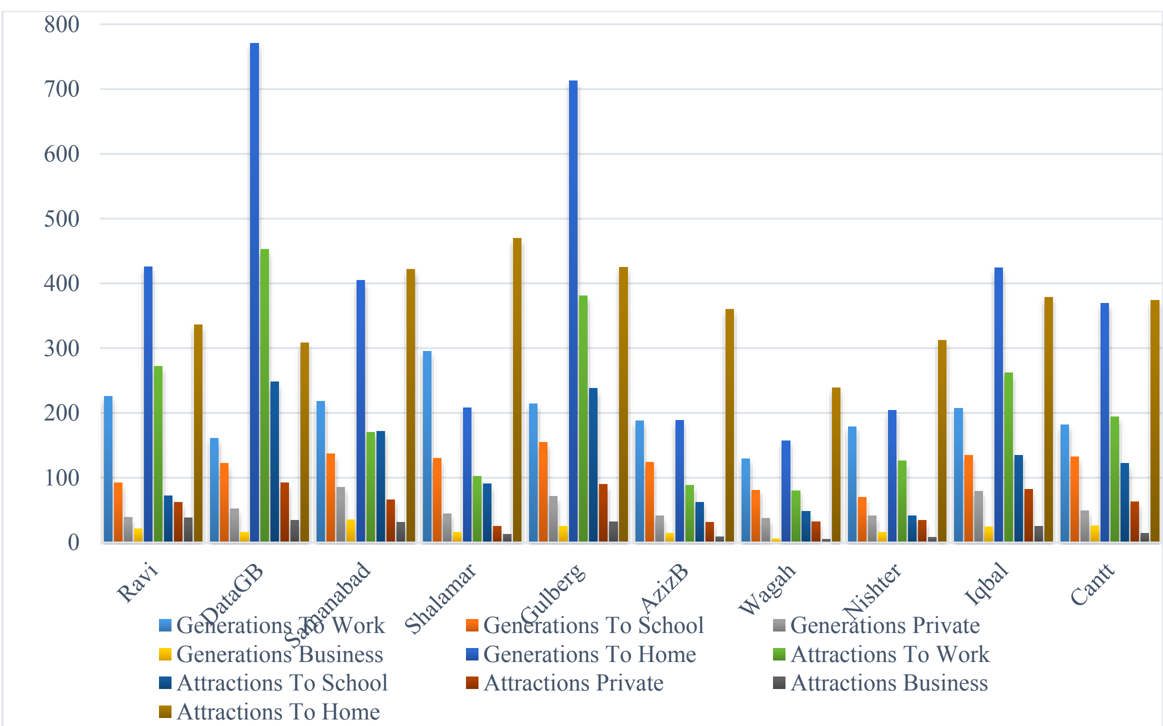


Figure 7.2 Town wise Trip Generation/ Attraction ('000/day)

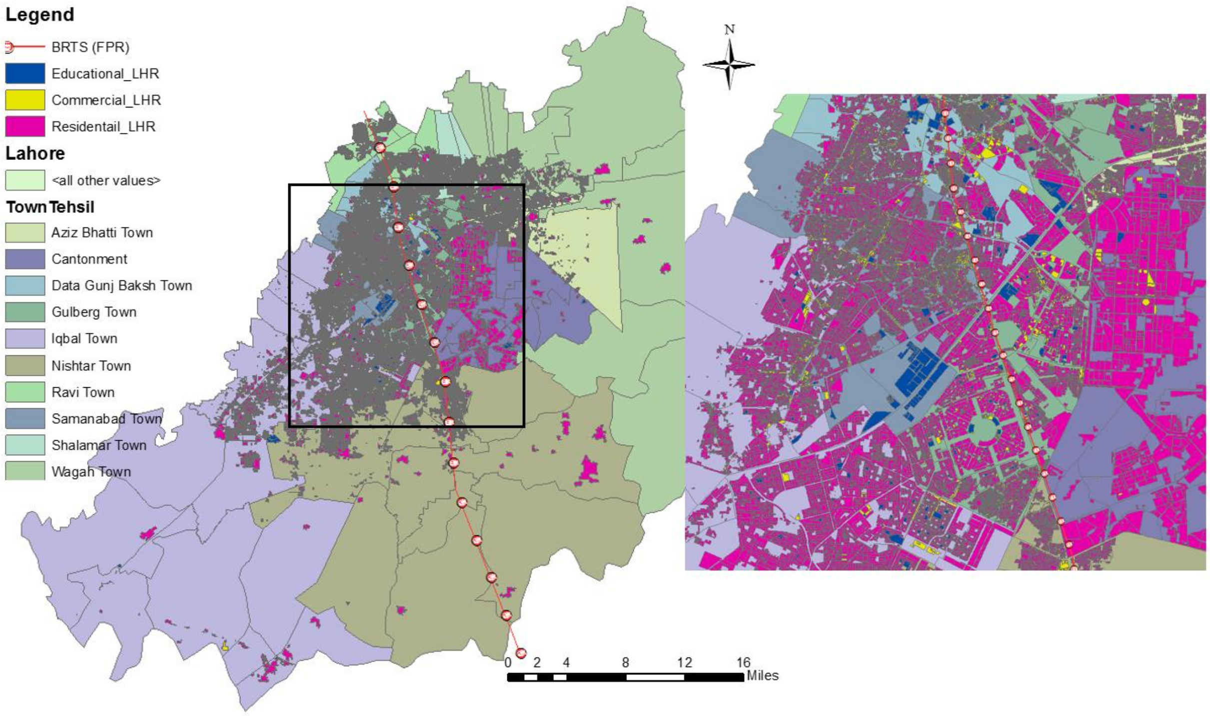


Figure 7.3 Distribution of Land Use Types within the Study Area

Table 7-2 Study Area 2010 Population by Town

No.	Town	Area (Km^2)	2010 Population ('000)	Density (Persons/ ha)
1	Ravi	31	1,007	328
2	DataGB	31	970	317
3	Samanabad	38	984	262
4	Shalamar	24	854	350
5	Gulberg	44	778	178
6	AzizB	69	667	97
7	Wagah	440	656	15
8	Nishter	497	945	19
9	Iqbal	520	960	18
10	Cantt	98	831	85

density of Ravi, Data GB, Samnabad and Shalamar is extremely high due to the smaller size of the towns. The population in these four towns is almost 44% of the total study area population while the area of these towns is merely 7% of the total study area. These figures result in 75% population density within these towns that shows city center is highly dense and congested. However the population density of Wagah town shows quite low level of urbanization. This is due to the Government restriction on development for defense reason and lack of arterial roads to Lahore city center (LUTMP, 2010-2011). Therefore Wagah town is not considered further and skipped altogether. Among rest of the towns, the population density of Nishter is considerably lesser due to the larger size of the town. For such towns, the distribution of population gets significant importance for serving the area with feeder service. However based on the population density Samanabad, Shalamar and Aziz B towns are preferred being more residential and denser.

In addition to the population density, it is noted that distribution of population within a town can significantly affect the decision of providing a feeder service.

(i) Is population concentrated or dispersed at the town level?

The prime purpose of a feeder service is to enhance the accessibility of BRTS by providing far living commuters, a comfortable mode which can shift them to their nearest station efficiently. There is an increase in total accessibility with an increase in the stops served by the feeder service but further increasing the number of stops served beyond a point also leads to unwanted increase in waiting and riding times of the passengers (Chandra et al., 2013). A longer cycle length of a feeder service will result into overall longer travel time and so may be rendered as unattractive and inefficient for commuters (The cycle length of feeder service is the time it takes from leaving a BRTS station to arriving there again). Here comes the significance of population distribution within a town. A town that has dispersed population and served by a feeder service will cause longer in-vehicle travel time for commuters and subsequently longer cycle length for feeder and vice versa. Therefor it is vital to assess the distribution of population within a town prior to providing a feeder service merely based on general land use type and population density. The measure of population density relies in total land area even if some of the land is sparsely populated.

(ii) Gini Coefficient (G) of Population Distribution

In order to measure the distribution of population within a town, Gini coefficient (G) is used which is a measure of inequality of a distribution. . It was developed by the Italian statistician Corrado **Gini** and published in his 1912 paper "Variabilità e mutabilità" ("Variability and Mutability"). It tells the extent to which the population density varies across an urban area. It is based on the Lorenz Curve; a cumulative frequency curve that compares the distribution of a specific variable (in this case, population density) with a uniform distribution that presents perfect equality. A Gini coefficient of zero expresses perfect equality, where all values are the same (for example; where every census tract of the town has same population). A

Gini coefficient of one (or 100%) expresses maximal inequality among values (for example, where all the inhabitants live on a single census tract of the town, and all other tracts have none).

For the study purpose, following equation (1) is applied to calculate the G value, without direct reference to the Lorenz curve.

For a population with values *yi*, *i* = 1 to *n*, that are indexed in non-decreasing order (*yi* ≤ *yi*+1):

$$G = \frac{1}{n}\left[n + 1 - 2\frac{\sum_{i=1}^{n}(n+1-i)y_i}{\sum_{i=1}^{n} y_i}\right] \qquad (1)$$

Where; n = number of zone and y = density

G-value results show more non uniform population distribution in AzizB and Nishter Town that further dictates that these towns own few denser and few sparsely populated zones (Fig. 7.4). This fact is also supported by visually comparing the landuse pattern as shown in Fig. 7.5. On the other hand Samanabad and Shalamar have a lower G value that shows relatively uniform population distribution all over the town area. These towns can be considered more feasible for initiating feeders, since uniform spread of population will be helpful in identifying the feeder route within a certain town. Depending on the available right of way or connectivity, feeder routes can be worked out, serving maximum population. However the towns with higher G values (AzizB and Nishter), should not be ignored at all. These towns require deeper observation regarding their perspective denser zones for routing feeders.

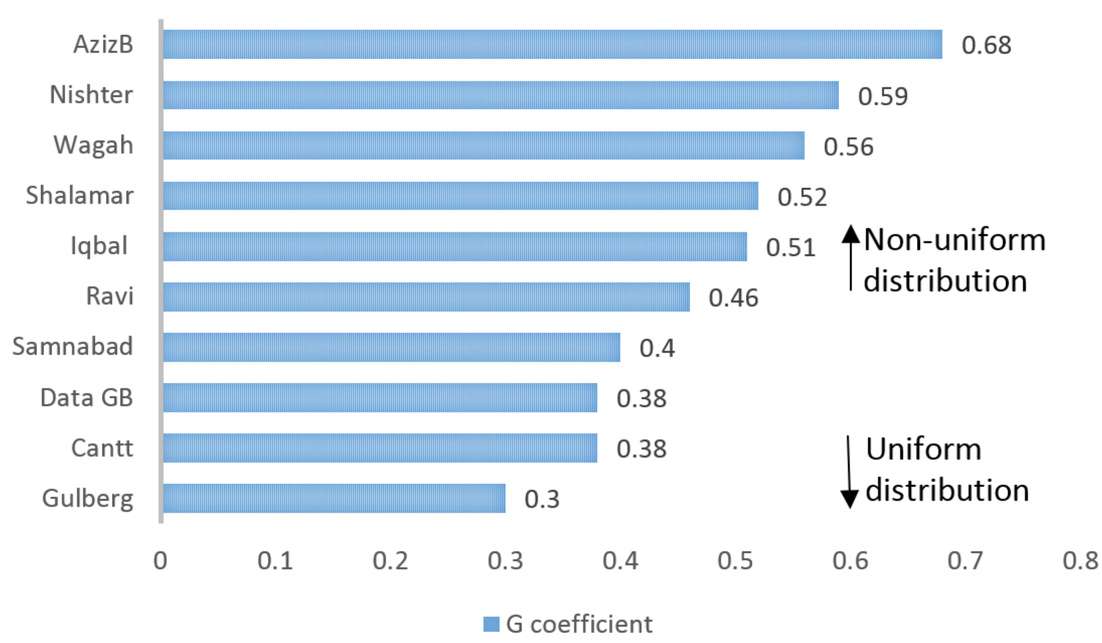


Figure 7.4 Gini Coefficient of Population Distribution per Town

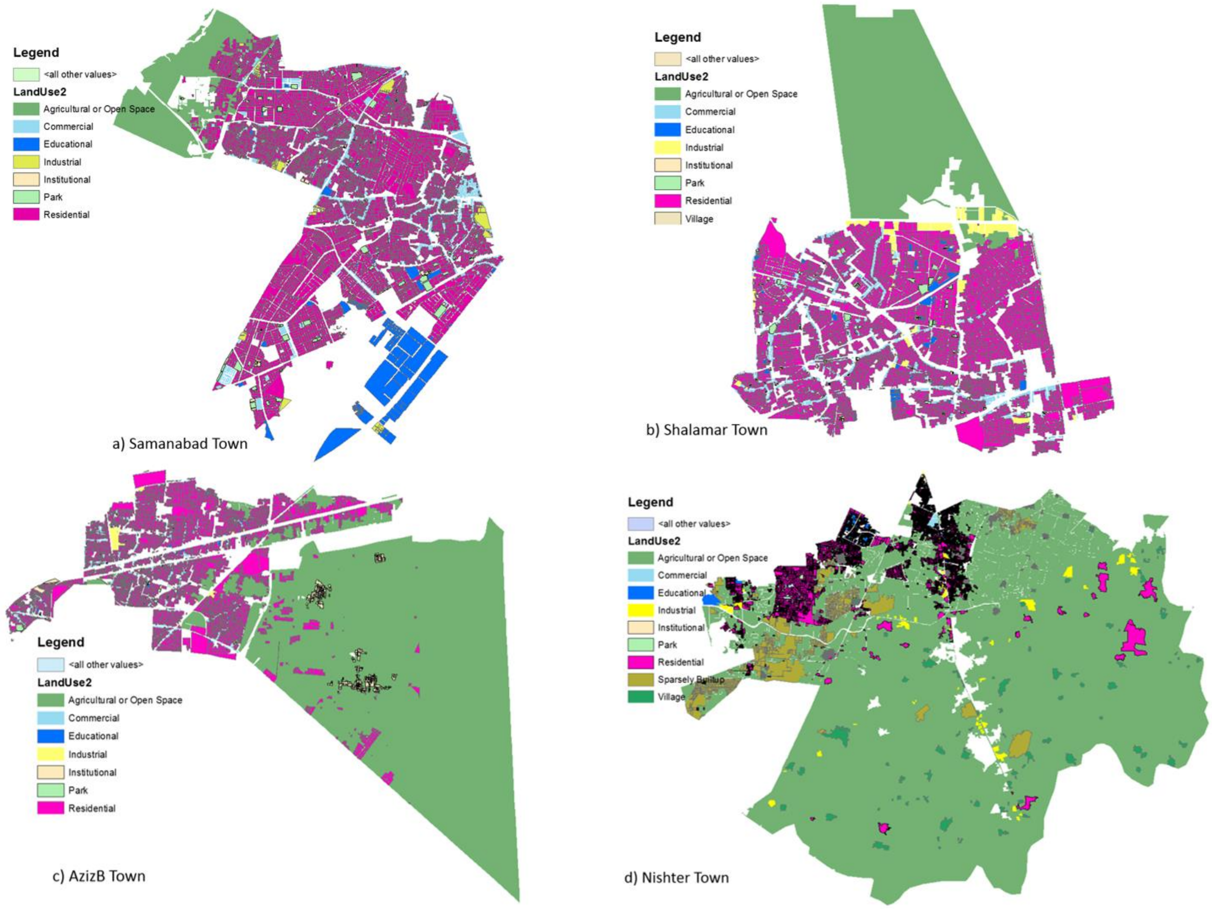


Figure 7.5 Landuse Distribution within Towns

7.2 SUMMARY

This chapter shows that it is essential to know the potential service areas for these feeders, which can offer access to maximum commuters. A residential landuse type will generate significant ridership for feeders and subsequently for BRT. Also the uniform population distribution within an area will produce efficient feeder routes with minimal delays. Considering these factors, Samnabad and Shalamar, are proposed to be served by feeders on priority bases. Provision of feeders within areas, generating higher demand will attract more commuters.

Chapter 8
DEVELOPMENT OF OPTIMIZED FEEDER ROUTES

This chapter provides the details of feeder routes generation. Feeder routes are worked out by solving an optimization problem. The optimization problem is solved by applying genetic algorithm where objective function is to minimize the travel cost. For the optimization purpose MATLAB Optimization tool box and MS Excel evolutionary solver are used. Firstly; conventional engineering approach is applied to generate the feeder routes, afterwards to address the shortcoming in the conventional method (as discussed in Chapter 2, section) improvements are introduced and applied. Lastly a comparison is set to see whether if results are improved. Following sections will provide details of the methodology adopted and the results generated.

8.1 FEEDER ROUTES GENERATION – INTRODUCTION

Designing feeder transit network for a main line haul system is an important aspect in the design of a good integrated transit route network. The problem to be addressed can be defined in the following general terms: given the transit demand locations for feeder area, and a description of the network, the aim is to determine set of feeder routes and allocate the transit units among these routes that correspond to a tradeoff between user and operator costs (Mohammad et.al. 2014). The problem of transit network design usually have conflicting objectives related to user's cost and operator's cost, and which can be formulated as an optimization problem. The user cost would be to minimize the overall travel time and at the same time maximize the comfort and convenience along the integrated network, whereas the operator would like to maximize the ridership and profit and at the same time minimize the vehicle operating cost, and fleet size for all the modes within the integrated mass transit system. Considering the users' view point shorter feeder routes yet accessible are desirable. The accessibility of the routes largely depends on the selection of potential demand locations/ nodes within an area. These potential demand locations should provide maximum coverage to maximum commuters and therefore must be carefully selected. Considering these factors feeder routes are generated, using conventional engineering approach as following:

8.2 FEEDER ROUTES DEVELOPMENT USING CONVENTIONAL ENGINEERING APPROACH

The overall methodology for the development of feeder routes is presented in Figure 8.1. In the conventional approach routes are worked out station wise. One BRTS station and two adjacent stations in both directions are selected. The methodology is explained in the following steps:

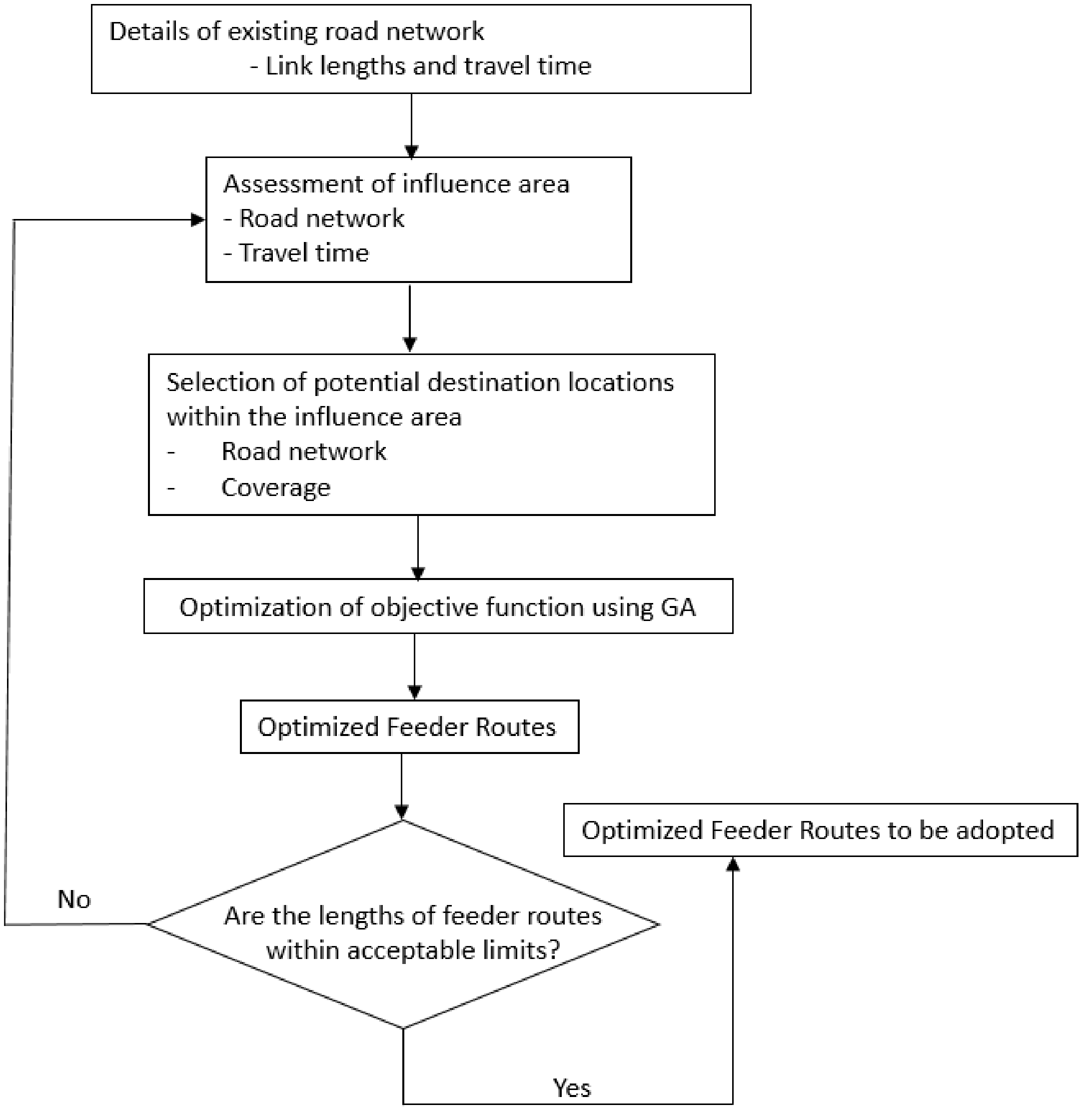


Figure 8.1 Methodology for the Development of Feeder Routes

8.2.1 **Steps Involved for Development of Routes**

Step 1

The very first step towards the feeder routes generation is the preparation of data. Following data is needed: details of the existing road network and BRTS corridor, link lengths and travel time. The data is acquired from city's master plan study (JICA, 2012).

Step 2

The target station, based on its proximity to preferred towns, proposed in chapter 7, and its adjacent stations are selected. Stations 16, 17 and 18 are selected ones, among 27 BRT stations (Figure 8.2).

Step 3

The potential influence area for each of these stations is identified based on the road network and proximity to the respected station. It is observed that station 16 has considerably larger influence area than that for the other two stations, due to higher road connectivity and good road network around the station. Even few far located places have good access to station 16, than others.

Step 4

The potential demand points/nodes/stops are placed within the influence area for each station, such that spacing between any two adjacent stops should not exceed 1 km; beyond the walking distance (this is to maximize the route coverage). As presented in the Figure 8.2, each node is connected to a certain station, showing its corresponding serving station based on the road network and connectivity. These nodes are used as route generating nodes; 13, 4 and 6 nodes for 16, 17 and 18 stations respectively are identified that total make up 23 route generation nodes.

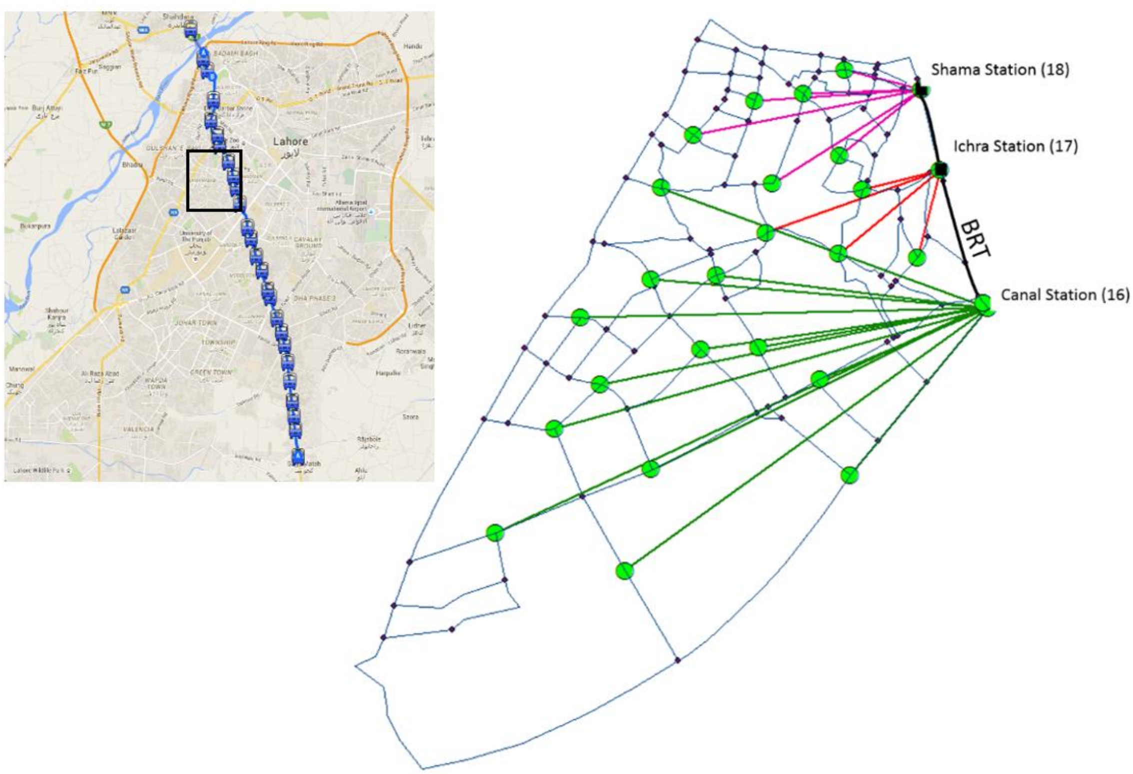


Figure 8.2 Selected BRT Stations and their Respective Route Generation Nodes/ Potential Demand Points

Step 5

A travel distance matrix is prepared for each station; between their respective nodes and corresponding stations.

Step 6

The travel distance matrix is converted to travel time matrix in 'minutes' using an average speed of 20 KPH to address the existing congestion level and road geometrics of the influence area (Wilson 2000) (Table 8.1a,8.1b, 8.1c). Travel time matrix is representing the cost matrix; since here cost is travel time.

Step 7

An objective function is defined in which the fitness function is to minimize the travel cost that is travel time and routes are generated.

8.2.2 **Initial Building Method and Application of GA**

The problem is solved as vehicle routing problem considering TSP; Travelling Salesman Problem, one of the most intensively studied problems in computational mathematics. TSP is modelled as an undirected weighted graph, such that route generation nodes/potential demand nodes are the graph's vertices, routes are the graph's edges, and a route's cost is the edge's weight. It is a minimization problem starting at a specified vertex after having visited each other vertex exactly once and finishing at the last vertex. The problem is formulated as *symmetric TSP*, assuming the distance between two nodes is the same in each opposite direction, forming an undirected graph. The solution of TSP is the best sequence of route generation nodes/stops starting from BRT station with minimum cost.

For implementing GA, permutation encoding is used. Permutation encoding is used in ordering problem, in which every chromosome is a string of number that represents a position in a sequence (Obitko 1998). Having decided on the representation/ encoding, the first step in the simple GA is to create an initial population or initial parent pool of solution. This is done by generating the number of individuals using a random number generator. The best solutions which are minimized routes for different cases are obtained against certain GA parameters.

8.2.3 **Route Generation Scenarios**

Feeder routes are generated considering; a route should start from the BRT station and visits all the corresponding nodes once, such that sequence of stops would yield minimum of total cost. Also none of the routes should either exceed 30 minutes in total travel time or should exceed from 10 km length. 30 minutes travel time is the acceptable limit for a feeder route to be adopted. Longer feeder lengths are not only unattractive for commuters but difficult for maintaining schedule.

Table 8-1 Travel Distance Matrices

a) Canal Station (16)

Node	1*	2	3	4	5	6	7	8	9	10	11	12	13	14
1*	0	11	12	19	17	19	14	15	14	22	19	7	5	9
2	11	0	4	7	5	6	3	6	8	10	10	8	6	3.6
3	12	4	0	7	5	7	3	4	8	12	18	8	7	2.55
4	19	7	7	0	6	2	4	10	5	9	11	13	10	7.5
5	17	5	5	6	0	5	3	8	7	9	11	12	11	7.8
6	19	6	7	2	5	0	6	10	5	5	6	12	12	9.6
7	14	3	3	4	3	6	0	4	7	11	11	9	9	5.1
8	15	6	4	10	8	10	4	0	12	16	18	13	10	6.6
9	14	8	8	5	7	5	7	12	0	5	5	12	7	6.6
10	22	10	12	9	9	5	11	16	5	0	6	16	12	11.7
11	19	10	18	11	11	6	11	18	5	6	0	13	16	11.7
12	7	8	8	13	12	12	9	13	12	16	13	0	6	6
13	5	6	7	10	11	12	9	10	7	12	16	6	0	4.5
14	9	3.6	2.55	7.5	7.8	9.6	5.1	6.6	6.6	11.7	11.7	6	4.5	0

b) Ichra Station (17)

Node	1*	2	3	4	5
1*	0	3.6	4.5	6	7.2
2	3.6	0	3.6	2.25	3.6
3	4.5	3.6	0	3	5.4
4	6	2.25	3	0	2.4
5	7.2	3.6	5.4	2.4	0

c) Shama Station (18)

Node	1*	2	3	4	5	6	7
1*	0	3.9	8.1	5.4	2.6	10.5	6.6
2	3.9	0	3.3	3.0	3.3	6.3	3.9
3	8.1	3.3	0	3.3	5.7	3.0	3.0
4	5.4	3.0	3.3	0	5.7	3.0	3.3
5	2.6	3.3	5.7	5.7	0	9.0	5.4
6	10.5	6.3	3.0	3.0	9.0	0	2.7
7	6.6	3.9	3.0	3.3	5.4	2.7	0

Considering these aspects and as per the results, three scenarios are generated and compared. Each scenarios produced two main outputs 1) Average feeder route length 2) Sum of all feeder route lengths.

From user view point, route should be of minimum average feeder length since passengers' in-vehicle travel time is directly affected by route length and is more important in case of feeder, as a feeder trip includes transfer activity. Ridership increase for the major transit is expected if the feeder transit provides passengers a timely access to these transfer (Bhat, et.al 2013).

However sum of all feeder route lengths generated in one scenario is of more interest to operators' side. Though commuters are more prone to use shorter feeder routes, which would eventually make their operation feasible.

Scenario – I

Initially one route is generated for each station yielding 3 routes, and it is called as Scenario-I (Figure 8.3a). Shorter feeder routes are generated for stations 17 and 18, of 12.6 and 17.5 minutes route length. These routes are within the acceptable criteria set for the feeder routes. However for station 16, longer route is generated of 56.85 minutes, due to the larger influence area. This longer feeder route covers 13 destination points and cannot provide a timely access to BRT. The average feeder route length in this case came out to be 31.95 minutes, whereas the sum of all route lengths is 96.85 in terms of travel time.

Scenario – II

Based on the results of Scenarios-I, influence area for station 16, is divided into two parts, so that shorter feasible feeder routes may generate. However the routes for station 17 and 18, remains the same as previous. The division of influence area is done considering proximity of nodes. For this case travel time matrix is divided into two parts and two routes are generated of 27 and 36.75 min lengths (Figure 8.3b). Ratio of the stop for these two routes is 6:7. In this scenario, one route length is still greater than the specified limit viz. 36.75 min, serving 7 stops. The average route length came out to be 26.7 min, whereas sum of all route lengths is 106.8 min.

Scenario –III

Considering the results of Scenario-II, influence area of station 16 is sub divided into three parts to achieve shorter feeder lengths. The nodes are grouped based on their nearness with each other. In this case travel distance matrix input is divided into three matrices. This resulted into three routes of 15.6, 24.75 and 29.1 min length; whereas ratio of the stops is 4:5:4 respectively (Figure 8.3c). All the generated routes are within the specified criteria of route length. Average route length in this case is 22.35 min, and total feeder route lengths is 111.75.

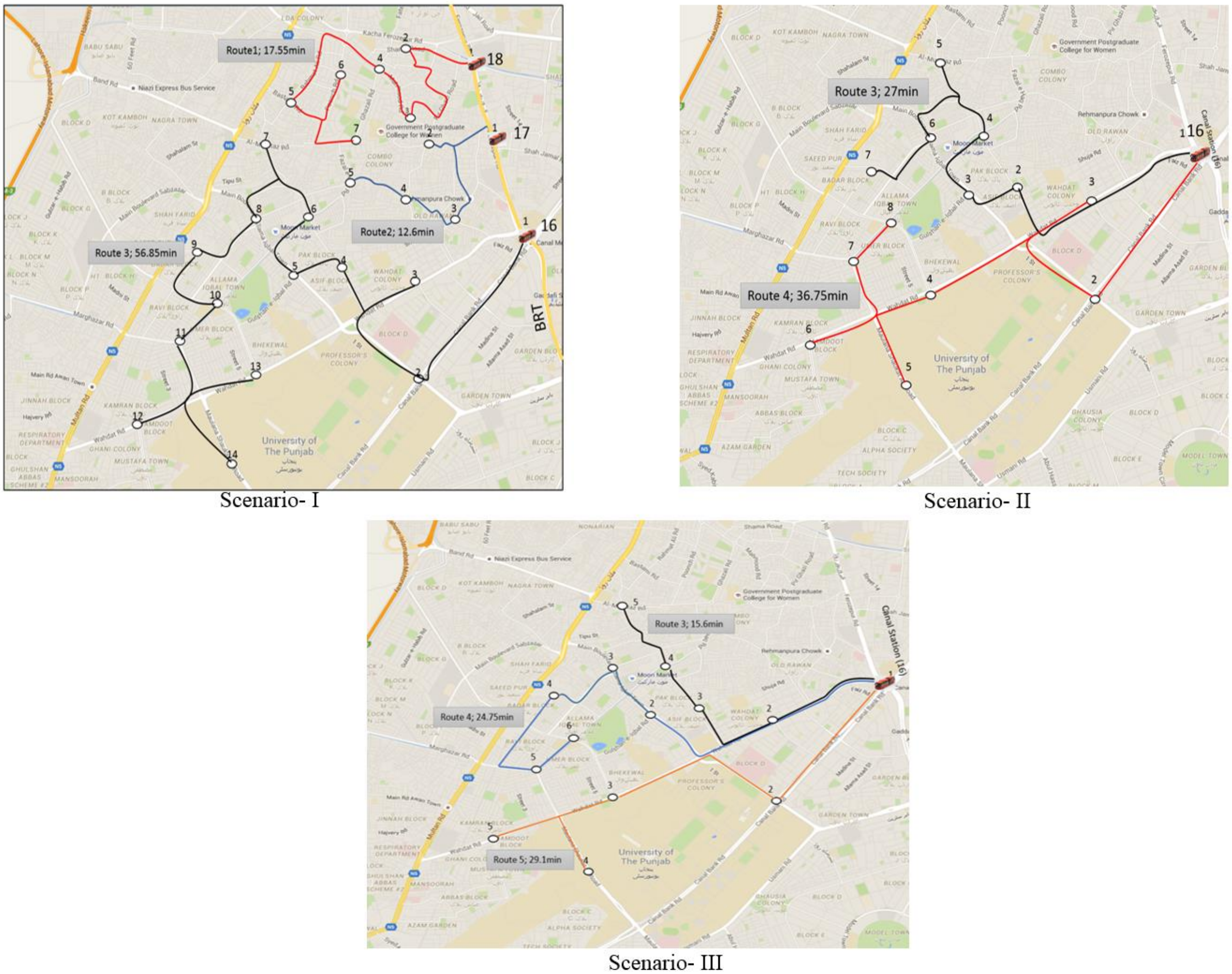


Figure 8.3 Feeders' Routes Generation Scenarios

8.2.4 **Results Discussion**

Three scenarios are built up using conventional approach towards route designing. Influence area for each station is identified based on the road network and geometry. The output of the problem yields the best sequence of the potential destination nodes, considering travel time as the cost measure. For each scenario, average route length and total length of all routes are calculated and compared (Figure 8.4). Results show that Scenario-III, generating 5 routes for three stations, yields the best results in terms of shorter route lengths (Table 8.2). However the sum of all route lengths is larger in this case. From the user viewpoint, this scenario is selected from the conventional approach method and plotted in Figure 8.5.

In this conventional approach, the routes are worked out separately for each station, based on the route generation nodes. Whereas the assignment of influence area and potential demand points/ route generation

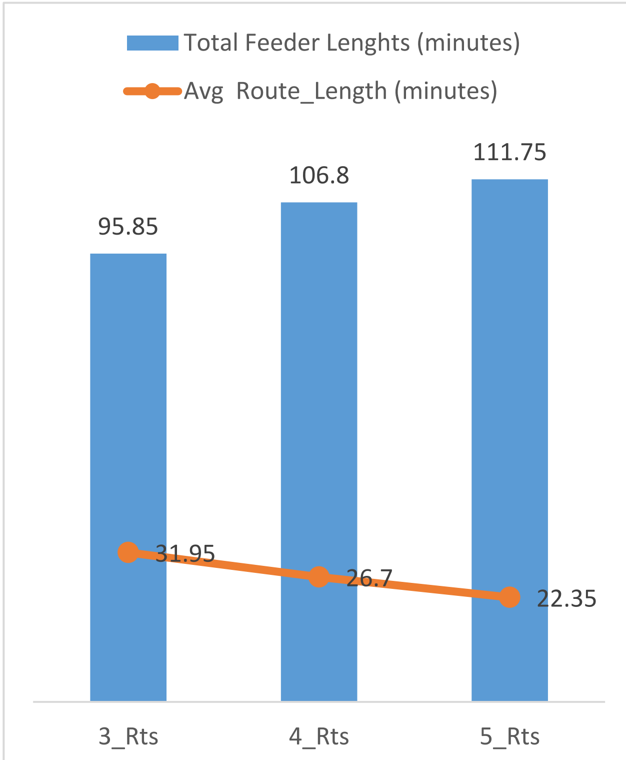


Figure 8.4 Comparison of Scenarios within

Table 8-2 Details of Selected Scenario

Route	Respective BRT station	Number of feeder stops excluding origin	Route length (minutes)
1	18	6	17.55
2	17	4	12.6
3	16	4	15.6
4	16	5	24.75
5	16	4	29.10
Total route length			111.75
Average route length			22.35

nodes is done prior to route development and mainly depends on the decision maker. This approach involves human biasness towards selection of particular nodes for a certain station. This human preconception and biasness affects the results in a way, that generated routes may not be the best ones. Not only this, a particular node may be nearer from a certain station, may not be that much nearer or becomes farther even, after inserting in the generated route for that station. Though, at this stage, this issue cannot be identified

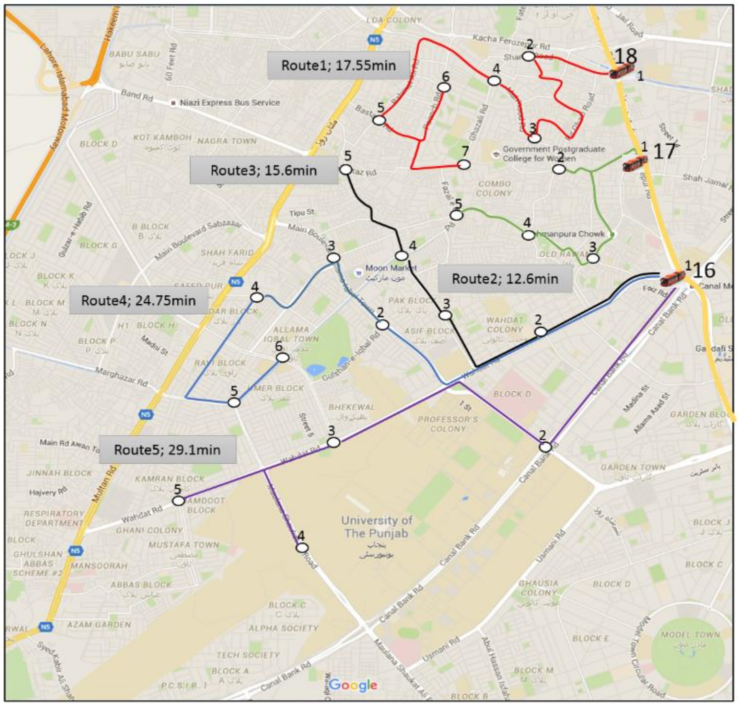


Figure 8.5 Generated Feeder Routes Using Conventional Method

for any of the route generation nodes. Also this approach results in repetitive route generation exercise one by one to cover the whole mass transit system which renders it inefficient. However this approach can be modified and results can be improved as discussed in the next sections.

8.3 FEEDER ROUTES DEVELOPMENT USING MODIFIED IMPROVED APPROACH

Feeder routes generated by conventional engineering approach are improved after identifying the associated loopholes. Modifications are introduced to determine optimal routes in a more efficient and reliable manner. These modification are aimed to determine optimal routes for multiple adjacent stations simultaneously. Here the term 'simultaneous' addresses the drawback present in the conventional approach.

Simultaneous: Generation of routes for all (or multiple adjacent) stations, occurring at one time, will yield improved optimization results.

In the improved optimization approach, also the route generation points or influence area to all (or multiple adjacent) stations are not assigned prior to the route generation. Rather than these points are selected during the process of route generation based on the objective function which is 'to minimize the cost'.

8.3.1 Steps Involved For the Development of Improved Feeder Routes

For the improvement purpose the same very stations, which were previously used for conventional approach, are being used altogether. The overall methodology adopted, is presented in Figure 8.6., and explained in the following sections.

Step 1

Similar data that was used for conventional approach, was used consisting of details of existing road network, including link lengths and travel times, acquired from master plan study (JICA, 2012).

Step 2

All potential demand points are identified and selected as route generation points for all the stations, stations which are under consideration. The location of these points is based on providing maximum access/ coverage. Also BRT stations for which routes are being generated is a separate input for this case.

Step 3

Since all the route generation points are combined in one matrix, therefore it is conditional to provide the information regarding the maximum number of routes generated and minimum route length which is minimum number of stops in one route. These inputs are mandatory for this case as route generation points/nodes are not in split form or assigned to any of the station. However number of desirable routes is a measure of BRT stations i.e. one route is generated per station. In case where one station is decided to have more than one route, dummy stations have to be introduced equals to number of routes (Figure 8.7). For example two routes are to be generated for station 16, then for one route origin point is station 16 and for second route station 16a (same coordinates as of station 16) has to be provided.

Step 4

A travel distance matrix is prepared for all the route generation points and is converted into travel time using an average speed of 20 KPH to address the existing congestion level and road geometrics of the influence area (Wilson 2000) Travel time matrix is representing the cost matrix; since here cost is travel time.

Step 5

An objective function is defined in which the fitness function is to minimize the travel cost that is travel time and routes are generated.

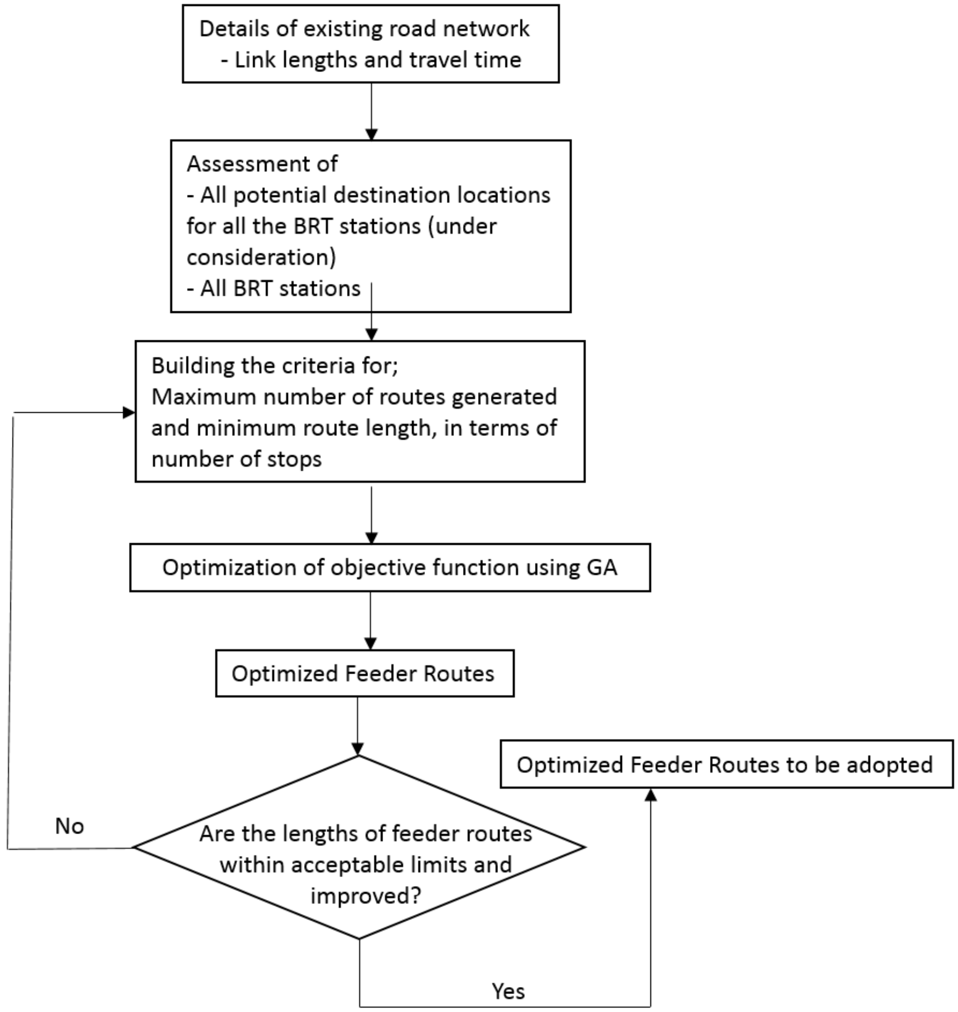


Figure 8.6 Improved Methodology for the Development of Feeder Routes

8.3.2 Problem Building Method

The problem is solved by introducing a variation in basic Travelling Salesman Problem (TSP). The initial building method is similar as previous in which route generation nodes/potential demand nodes are the graph's vertices, routes are the graph's edges, and a route's cost is the edge's weight. It is formulated as *symmetric TSP*, assuming the distance between two nodes is the same in each opposite direction, forming an undirected graph. A separate matrix for BRT stations/origin points showing their relative position in the graph helps the algorithm in selecting most appropriate route generation points for all stations, as per the defined objective function (Figure 8.7). TSP is solved using genetic algorithm and produces genetic algorithm solution to multiple stations with variable number of multiple routes. The output solution is multiple routes in best order of route generation points/nodes/ stops, for multiple BRT stations.

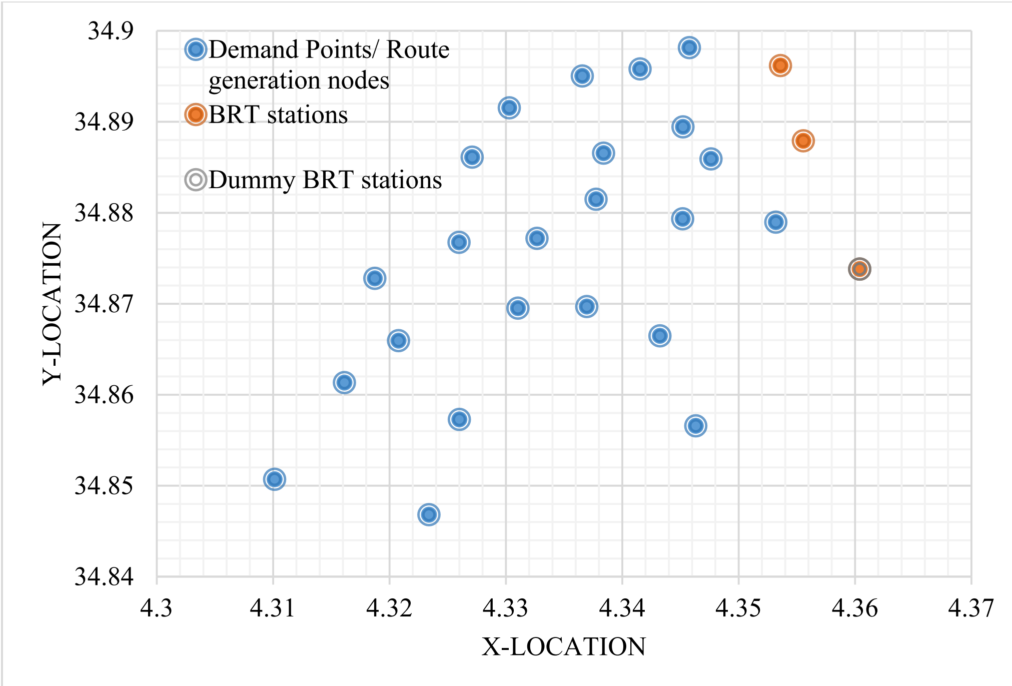


Figure 8.7 X-Y Location of demand points and BRT stations

8.3.3 **Route Generation Scenarios**

For the improved optimization, inputs regarding maximum number of routes and minimum number of stops in one route generated few scenarios. There are total 23 route generation points/ stops, to be used for route generation for three stations. Initially three routes per stations are worked out with varying number of 'minimum route length/ number of stops in one route'. For this case, variable of minimum route length started from 7, since the total available route generation points are only 23. Later on more routes are created including dummy origin points/BRT stations (Figure 8.7), which are assumed on station number 16, being more accessible with well-connected road network that resulted into number of scenarios (Figure 8.8). In each case the variable of minimum route length is decide by its divisibility with total available route generation points viz. 23. Various combinations are tested by varying number of routes and minimum route length to find the most feasible solution and illustrated in Figure 8.7, where x-axis shows the minimum route length in terms of minimum number of stops.

Among these scenarios, combinations that produce minimum of travel time, users' cost are selected and compared with each other to find the best solution (Figure 8.9).

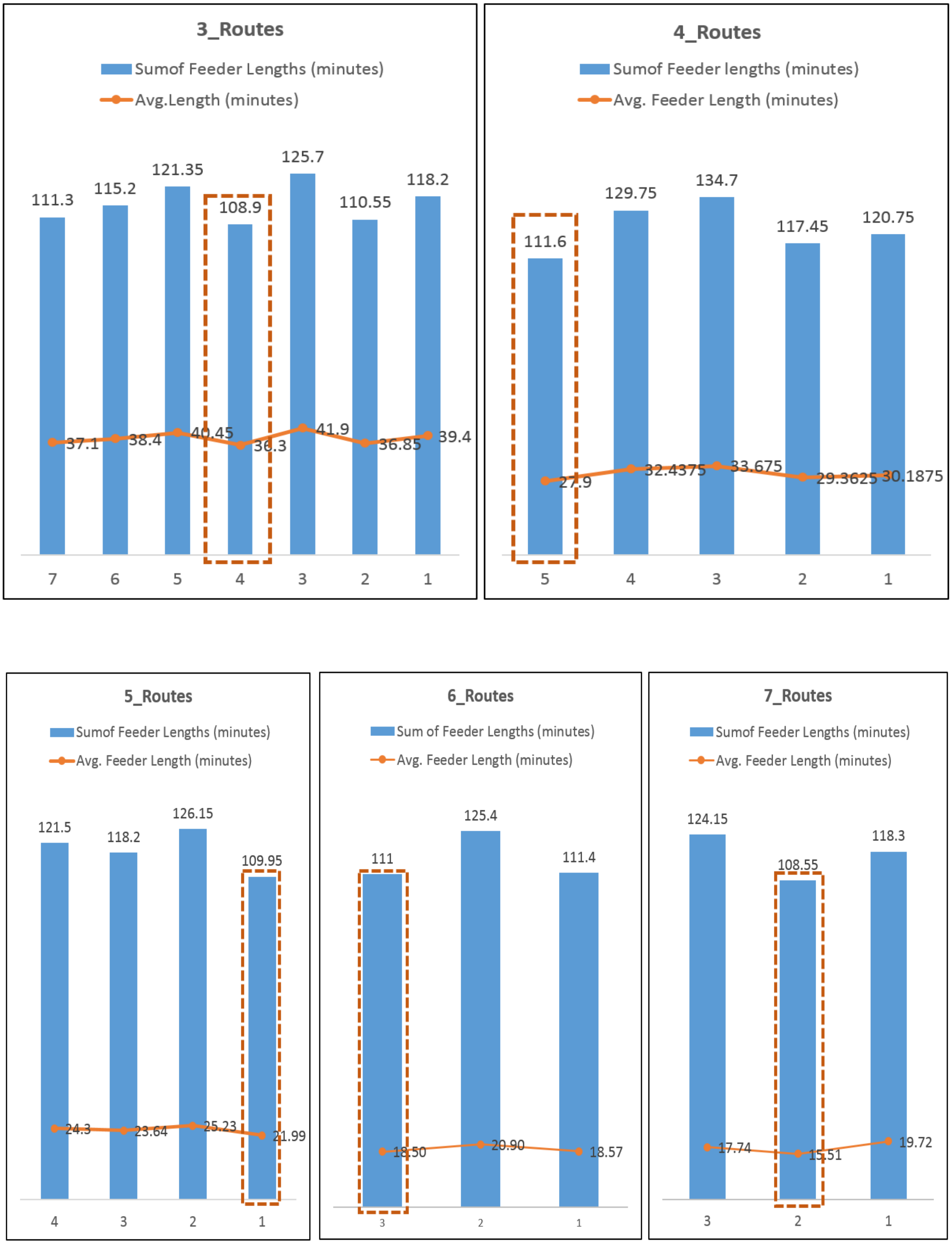


Figure 8.8 Various Route Generation Scenario with Varying Number of Routes & Route Lengths (minutes)

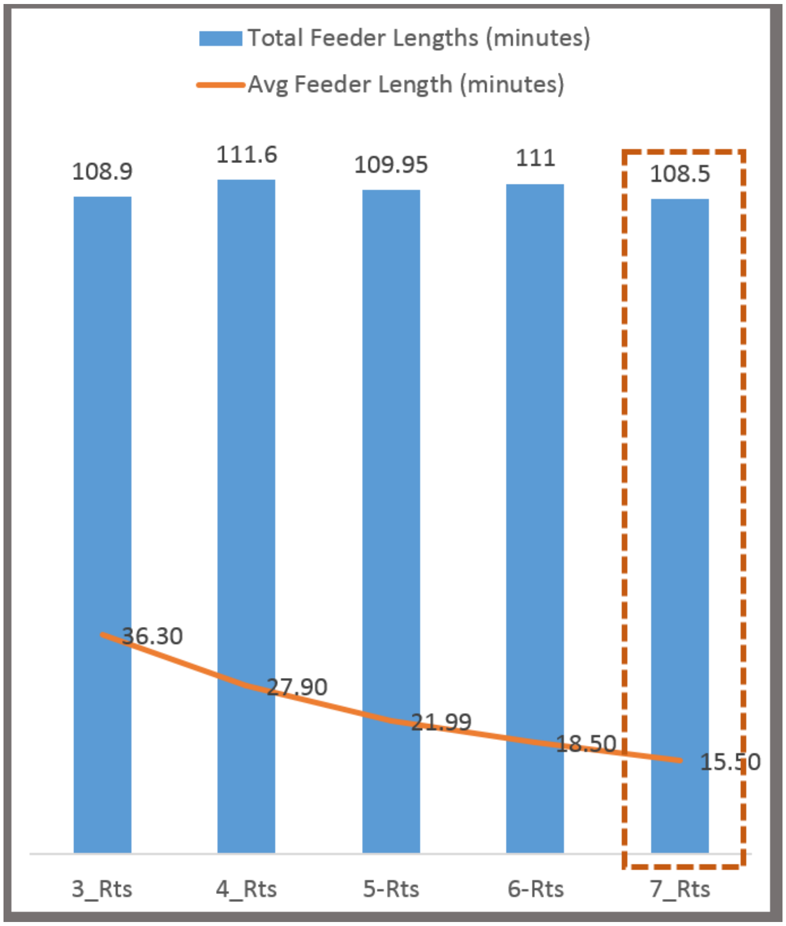
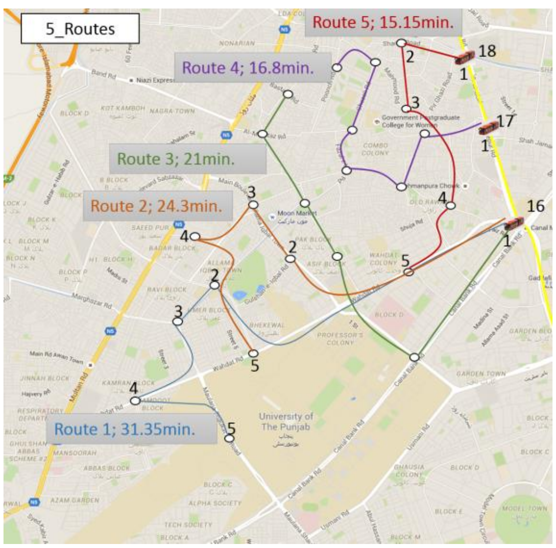


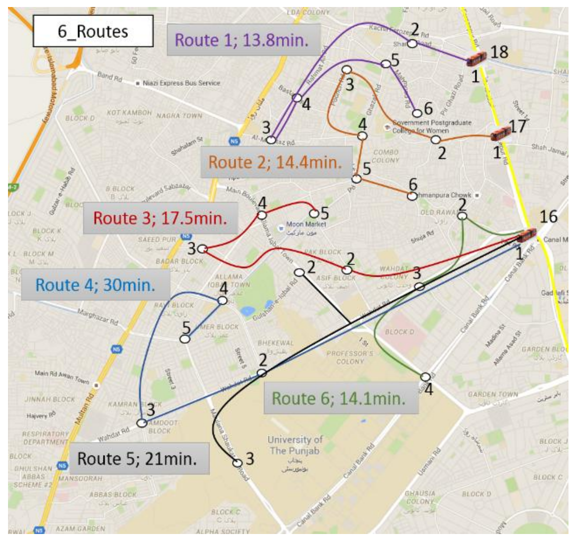
Figure 8.9 Comparison of Best Sets among Varying Number of Routes

8.3.4 Results Discussion

Several scenarios are built up with the choice of varying the number of total routes and minimum route length. The results show that the combination with minimum average route length offers minimum of total feeder route length as well (Figure 8.9). Here comes the difference between the two approaches; conventional and improved, and advantage of using 'simultaneous' approach. A simultaneous approach generated an overall optimized route network by selecting the most suitable route generation points for a certain station. The combination that generated minimum of the average route length from each scenario are compared as presented in Figure 8.9 & 8.10. It is noted that by increasing the number of routes, average route length is decreased.

Among these combinations 7_routes, generate better results not only in terms of average route length but also for total route length. The details of the combination are presented in Table 8.3 and plotted in Figure





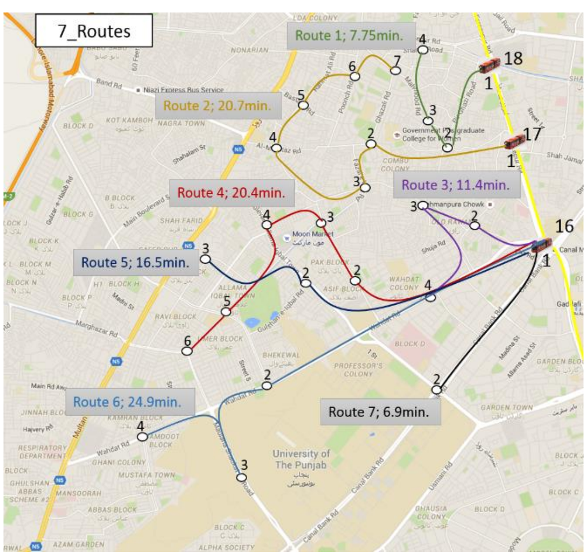


Figure 8.10 Graphical Comparison of Varying Number of Routes

Table 8-3 Details of Selected Combination

Route No.	Respective BRT station	Route length (minutes)
1	Shama (18)	7.75
2	Ichra (17)	20.7
3	Canal (16)	11.4
4	Canal (16)	20.4
5	Canal (16)	16.5
6	Canal (16)	24.9
7	Canal (16)	6.9

8.11. From the improved approach results, 7_routes combination is selected as the best solution. Further in the following sections, it is compared with the best solution from the conventional approach.

8.4 COMPARISON OF GENERATED FEEDER ROUTES THROUGH CONVENTIONAL AND IMPROVED APPROACH

8.4.1 Travel time comparison

Previously many researchers have solved feeder bus network design problem and developed models to get optimized results. All of these proposed models are applied at station level and routes are worked out per station using conventional engineering approach. The application of model for each station separately is linked with the increased probability of getting less optimum solutions. For example Shrivastava et. al. (2006) used genetic algorithm approach to propose a model for the development of optimized feeder routes and coordinated schedules and then the model is applied for one station, mentioning that: *'if a similar exercise was carried out by identifying the influence area of all stations shorter feeder routes would be developed which would be better for maintaining schedules'* (Shrivastava and Dhingra, 2001, cited by Shrivastatva et.al. 2006). Furthermore it is mentioned; '*This is due to the fact that a node may be connected to more than one station and its connectivity will certainly be better with a shorter connecting length from one particular station only'*. In this case, the presence of node in a network is accepted and identification of influence area for all the stations to get better routes, is proposed. But still it lacks the understanding of simultaneous approach where decision maker does not set influence area for any of the station. A node is a part of network and the fact of 'its connection with other stations and with other routes' must be incorporated while route generating process to get higher optimal solutions.

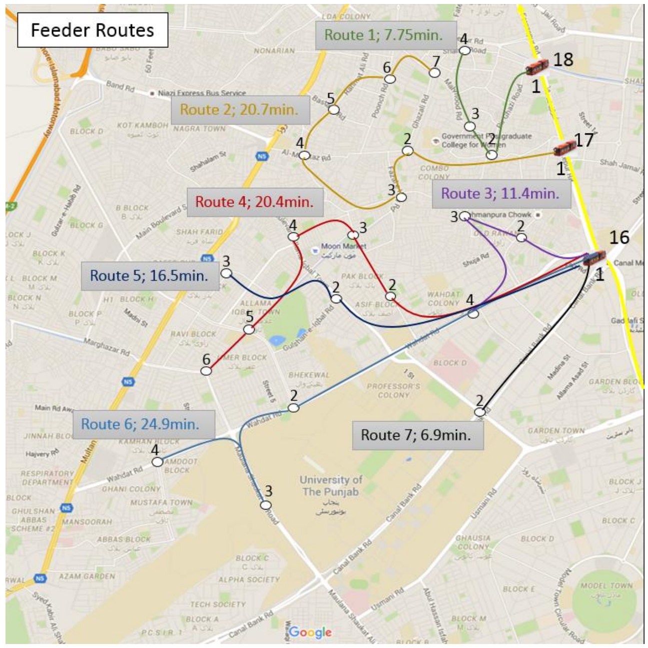


Figure 8.11 Generated Feeder Routes through Improved Approach

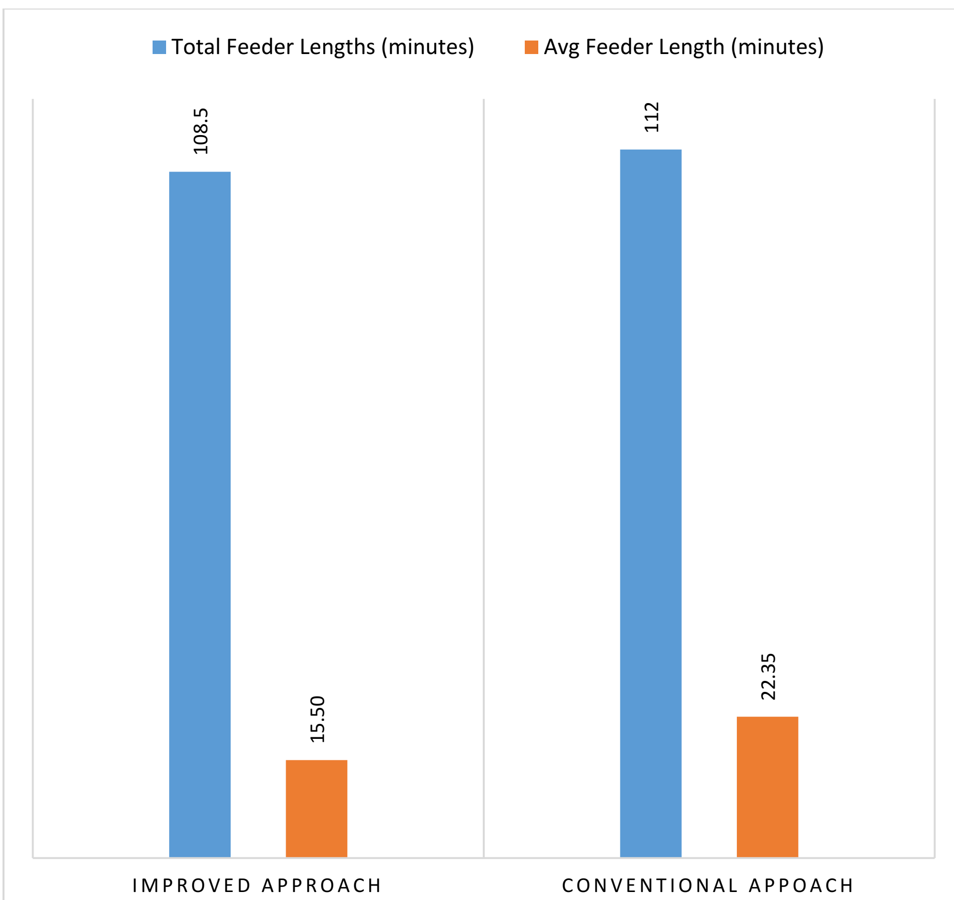


Figure 8.12 Comparison of Conventional and Improved Approach

Considering these aspects, initially the route are generated through conventional engineering approach. Few scenarios are built to make all the generated routes within acceptable limits of feeder route length. Later simultaneous approach is applied to improve the solution.

It is found that, in the conventional approach there is direct relation between the number of total routes and sum of all feeder route lengths; both increases side by side. Whereas average route length decreases as the sum of all route lengths increases (Figure 8.4). In this approach either average route length or sum of total route lengths can be controlled. It is impossible to control /minimize both at the same time. Average route length can be minimized by assigning fewer route generation points in one route but it will result into higher number of total routes. However sum of total route lengths can be minimized by reducing the number of total routes or by assigning more route generation points in one route. These two aforementioned objective conditions conflict each other and therefore only one of them can be achieved. From the users' perspective routes with lesser route length are feasible and will attract commuters. Since Passengers' travel time is directly affected by route length and timely access will increase the ridership of main transit (Bhat et.al. 2013).

Conversely unlike the conventional approach, the trend of increasing the number of routes is not directly proportional to the sum of total feeder routes length (Figure 8.9). The simultaneous approach minimizes both of the costs. The selection and insertion of all the route generation points altogether, maximizes the optimization and generates better results. Several scenarios can be built and analyzed by varying the number of routes and minimum route length. The minimum route length dictates the minimum number of stops in one route. It generates a set of solutions representing the best tradeoff among the confliction objectives. Not only this, this approach saves computational time and effort which is not possible otherwise due to repetitive route modelling exercise for each station and identifying the influence area for each station as well. This is an optimized and efficient approach to produce optimal solutions.

A comparison of results from the two approaches is presented in Figure 8.12. These results clearly indicate that improved simultaneous approach helped to reduce the total feeder route length and provided better solution. It creates a better balance between users and operators; two basic components of transport market, and results in an improved transport system. Well-functioned transport system should allow transport supply to meet transport demand so that transport needs for mobility and access are satisfied (Jean-Paul et. al., 2013). The simultaneous application of any model will result a true network based solution, considering the true sense of network where one node is not limited to only one station. The decision of assigning influence area consisting potential demand points as route generation nodes to one station might not be as good for the whole network, when other stations are considered. The application of improved approach particularly to the stations owing poorly assigned influence zone can generate dramatically improved results.

8.4.2 Operators' cost comparison

The target of the bus operators is to minimize the overall cost of operation of bus services. Therefore a brief comparison is developed between the costs from the two said approaches to see operators' benefits. For this purpose, per kilometre fleet size and bus operating cost is calculated. Since the demand generating/ attracting at each feeder stop and BRT station is unknown, 15 minutes frequency for feeder bus is assumed. Cycle time or round trip travel time for each route is already determined therefore number of buses required to operate the route follow from dividing the round trip travel time by the frequency. Fleet size calculations for the two approaches show analogues results (Table 8.4). Furthermore fleet operating costs are determined taking PKR (Pakistani Rupees) 35/- per kilometre (0.33USD/km) as unit cost. This reference unit cost is acquired from a renowned bus company operating in Lahore; Daewoo express bus service. The results for the operating costs show that lesser cost is incurred in improved approach (Figure 8.13). Although the fleet size is same but the fleet requires to traverse lesser kilometres in improved approach than that of in the conventional approach.

The comparison of the costs of the two approaches indicate that the improved approach is more feasible form operators' standpoint also. However with the precise information about demand pattern throughout the times of the day at each feeder stop and BRT station, frequency of feeder service can be altered accordingly.

Table 8-4 Fleet Size calculations

Typical approach			**Conventional approach**		
Route No.	Cycle length (minutes)	Fleet size per hour	Route No.	Cycle length (minutes)	Fleet size per hour
1	49.2	3	1	49.8	3
2	55.5	4	2	40.8	3
3	50.4	3	3	13.8	1
4	27.0	2	4	22.8	2
5	41.4	3	5	33.0	2
			6	41.4	3
			7	15.4	1
Total	223.5	15		217.1	15

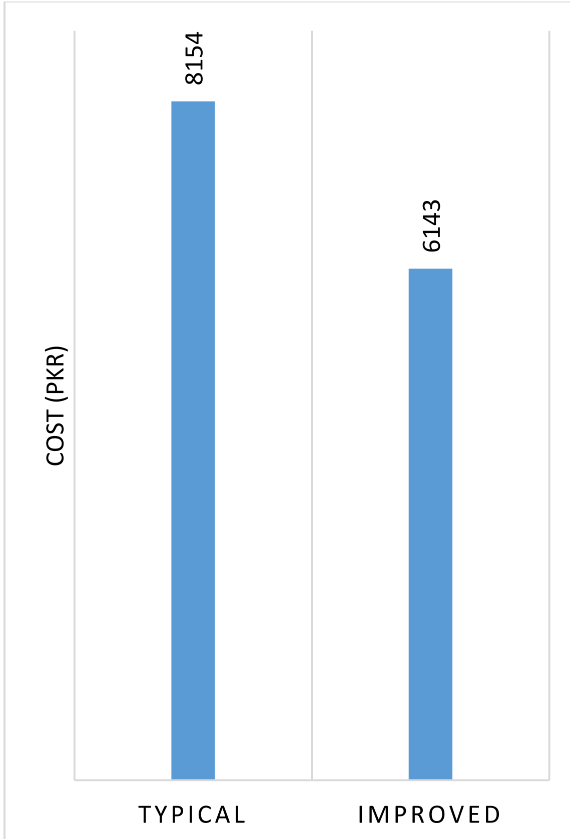


Figure 8.13 Fleet operating cost per hour

8.5 SUMMARY

This chapter presents the details of feeder route design. In this regard initially the feeder routes are generated through conventional engineering approach. Few scenarios are built and compared on the grounds of shorter average route length. The routes owing to lesser route lengths are selected from the conventional approach. Later, conventional approach is modified by incorporating the effect of 'simultaneous' route generation for multiple adjacent stations. The results from the improved approach shows better optimum solutions in terms of users' and operators' cost than that of conventional ones.

Chapter 9
CONCLUSIONS AND RECCOMENDATIONS

This chapter mainly includes the key findings assessed from the previous chapters. Further it formulates few policies regarding feeder services for a mass transit system which are based upon the study findings. Later it suggests the implications for other developing countries. Lastly it shows the potential prospects of the current study for future research.

9.1 SUMMARY OF STUDY KEY FINDINGS

9.1.1 Outcomes from Current Travel Pattern

The analysis of the current travel pattern in the Lahore city shows that BRT has not achieved the target of widespread ridership. There is no diversity in social income class among the most frequent BRT users. All of these belong to low income class and have no other travel choice than travelling publically and so are transit captives. Surveys conducted at BRT nearby workplaces, resulted the same group of users, even though they have some employment or source of earning. In these offices or workplaces lower-income staff is the one who use BRT to commute on daily basis. Rest of the work commuters are choice riders and so use private vehicles (motorcycle or car) for commuting and belong to middle or high income classes. None of the choice riders had found to be frequent BRT users. Commuters owning private vehicle are more prone to use these for commuting purposes even if their workplace is located near/ within walking distance (>1 km) from BRT station.

The commuters who live or/and work near BRT stations are found to use BRT consistently. For such trips, access or/and egress part is mostly done by walk only, due to the nearness from the station. However majority of these trips includes walk for the egress part and this is due to the location of BRT corridor. BRT corridor targets several key locations of the city and provides direct access to many offices/ activity centres and hubs. Proximity of workplace location from BRT station in which one can walk to the office from the station is found to be more influential in making BRT trip. This trend is an obvious advantage of BRT location and can be triggered in future to attract commuters.

Currently BRT has no regular feeder service and therefore is fed by existing travelling modes comprising public transport (bus) and paratransit (motorcycle rickshaw). Among these two public transport is poorly designed in terms of routes resulting deprived spatial coverage. Majority of the city's residents are living without access to these public buses. This shows their inefficiency in providing access and to be used as a feeder mode. The insufficient coverage of public transport represents their malfunctioning not only as feeder but as main travel mode also. These underprivileged public transport raised the use of paratransit as a major feeder mode. These paratransit are mobile enough to penetrate through the residential streets but commuters are not satisfied by the service quality of these vehicles. Commuters perceived; passengers' comfort and convenience, safety during travel, route reliability and environmental issues (specifically noise emission) as the most dissatisfied factors, while using paratransit. These factors are fairly associated with the vehicle quality (being used as paratransit) and the operation of the service.

BRT accessibility is significantly affected by the demerits of its current feeder modes. In order to boost the accessibility it is conditional to remove all the negative factors which are linked with the feeders. The inefficient and insufficient accessibility conditions signify the potential of a regular feeder bus. A regular feeder bus is a regular vehicle, route reliable as that of public transport and will be safer, comfortable and generate less emission as compared to paratransit. Commuters show strong willingness to pay for the new regular feeder service, which if replace the paratransit will enhance the accessibility.

9.1.2 **Outcomes from Feeder Network Design**

A regular feeder bus requires a vigilant planning for a feasible and cost effective operation. The information about landuse type is found to be beneficial for identifying the potential demand areas for feeder bus. Residential towns can generate sufficient feeders' ridership, since BRT provide direct access to most of the city's workplaces. The requirement of a regular feeder that can shift commuters from their origin (residence) to the nearby BRT station is obvious. The landuse type information can also be helpful in identifying the peak demand times of the day and so the demand frequency. A residential town, which is recommended for feeders, will generate more 'to trips' in the morning and 'from trips' in the evening and this fact is valuable in scheduling the feeders. Among the residential towns, towns with higher population density are selected since higher densities increase the cost efficiency of public transit services. For designing the feeder routes distribution of density viz. the information where the density is more critical. A dispersed density will generate longer routes and will cause the feeders inefficient and unattractive. For this purpose uniformly populated towns are further recommended. The feeder routes within these towns can be worked out, keeping the routes smaller and serving the most demand.

Feeder routes should be worked out as a solution of optimization problem. The optimized feeder routes provide high coverage yet shortest. The application of GA for solving route optimization problem is recommended since it increasingly finds the better solution and specific genetic operators ensure to find the global minima or the best solution. The selection of the route generation nodes/demand points/stops should be carefully done as it leads the way for successful development of feeder routes. The conventional engineering approach for the route designing should be improved. And instead the proposed improved approach should be applied for route generation. The improved simultaneous approach generates better optimal solutions. This approach shows that selection of route generation nodes and route building for one station should be carried out for all (or multiple adjacent) stations at one time. It generates route with better balance between users' and operators' cost. The application of improved approach for feeder route generation saves computational time and effort and therefore produces efficient and optimal solutions in an efficient manner.

9.2 POLICY DEVELOPMENT

This section provides the details of the proposed policies according the study findings:

BRT Accessibility improvement policy

This policy aims to improve the overall BRT accessibility conditions. It is intended to not only attract more ridership but also to satisfy the current riders. Following are the proposed strategies under this policy

- The level of service offered by current paratransit must be improved in terms of vehicle quality. Few mechanical improvements should be applied to the vehicle to make the paratransit trip comfortable, safer and environment friendly. The rage driving due to inexpert and underage drives which puts passengers' life on risk should be controlled by the authorities. The route reliability should also be improved, for which routes should be regulated and monitored by enforcement bodies.
- Routes for the conventional public transport should be redesigned to increase their service area/coverage. Comfort and safety of these current public buses should be improved. There should be continuous maintenance strategies for these buses which will make them comfortable and safer.
- There should be strategies for initiating a quality feeder service in the form of regular feeder bus. A regular feeder bus is a sustainable mode of travel that will be helpful in attracting choice riders, living far from BRT corridor. It is regular vehicle that cannot be restricted in certain area due to either 'inappropriate looks' or 'safety and environmental risks', like that for paratransit.

Feeder routes improvement policy

This policy is to adopt the improved route generation technique to get higher optimized routes. It proposes the following strategies.

- Appropriate strategies should be built to make the operation of the proposed regular feeder bus efficient. The adoption of improved route generation approach will yield highly optimized routes that can attract commuters, being shorter and yet will not be a burden for the operators due to the smaller overall length. The improved approach is also beneficial for the decision makers since it saves computational effort and time.

9.3 IMPLICATIONS FOR THE DEVELOPING COUNTRIES

Developing countries are highly striving for transit development to alleviate the increasing trend of motorization. Although many of these have implemented efficient mass transit systems but accessibility of these systems still remains crucial. It is one of the main reason that these systems are still far away from the target and could not succeed in attracting diverse income classes other than low ones. For all the developing countries it is the time to understand that efficient mass transit systems do need efficient feeder system as well. Feeder bus is a sustainable solution which is free from the demerits as in case of paratransit. A regular feeder bus provides comfortable safer environment friendly access to mass transit stations, if planned carefully. To initiate such regular services, deep examination of landuse pattern will be beneficial in identifying the potential demand areas that are most in need.

As far as the role of paratransit as feeder mode is concerned, unlike the study area, several kinds of paratransit services are operating in developing countries; each has effective service area and potential passengers. Therefore the countries with various paratransit services, it is mandatory to evaluate them on the grounds of service area, potential passengers and feeder vehicle quality before implementing them as feeders for ALL. Commuters belong to diverse social income classes, have different preferences and choices that must be considered while recommending paratransit as a regular feeder mode. Also these existing paratransit must be modified and considering the study results, improvements in vehicle quality should be given priority. The other differences in local circumstances of various developing societies must be incorporated while improving the paratransit services.

On the other side, a regular feeder bus requires a vigilant and careful planning to achieve the target, when it has to operate in developing countries, where public transport is considered inefficient, uncomfortable, unreliable and so unattractive. In this regard transport planners do require innovative solutions to make these services attractive and viable choice for all. Shorter feeder routes can become a key to attract commuters, however route generation is a kind of optimization problem where a route has to serve certain demand points, to increase accessibility, yet shortest. Shorter route lengths will cause passengers to spend lesser travel time without excessive delays during feeder phase. The improvements proposed in conventional engineering approach can generate better optimized feeder routes, providing better trade-off for operators also; operators in developing countries have limitations due to limited resources.

9.4 FUTURE PROSPECTS

The current study has certain limitations that can be explored by more researchers. Each aspect of the study has potential in it that should be unveiled in future. The study is focussed to the study area Lahore that has a particular paratransit. In future more paratransit can be evaluated on other grounds by incorporating more variables. In this evaluation other social income classes can be taken on board. The perception of choice riders towards paratransit can be vital in assessing its role as feeder. Moreover feasibility of regular feeder bus can be studied in detail from supply side i.e. from operators' viewpoint. The operational requirement for running a feeder bus should also be studied in detail. The selection of potential feeder service areas can be made more confined from town to zone level. Some other landuse factors like road network inventory considering the feeder vehicle should be evaluated to find the most suitable service areas. For feeder route generation process, the accurate selection of route generation nodes will result in successful feeder routes and for that demand data can be acquired to build demand matrix. Also route generation problem which is an optimization problem, is studied as single objective function, however the same improved approach can be elaborated in future by applying multi objective functions or penalized objective function. Not only this some specific constraints can also be formulated from supply and demand side and the problem can be solved with these constraints. Moreover, the new feeder system may cause abrupt changes in travel patterns, and conditions around the BRT stations. The new system will attract more number of commuters that may result higher walking activities around the stations due to transfer, or unbalance between demand (attracted commuters) and capacity (BRT fleet). Therefore the impacts of the feeder service should be examined and studied as a post valuation of BRT system.

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- Saadia, T., Tanaka, S., Nakamura, F., (2016) Improving Access Considering Commuters' Perception (A case study of Lahore BRT), *International Journal of Innovative Research in Engineering and Management* 3(4), pp. 283-289.
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APPENDENDEX – I

QUESTIONNAIRE SHEET FOR THE FIRST FIELD SURVEY

(Conducted during March 2015)

METRO BUS USERS' SURVEY

Surveyor Name: ________________ Location: _______________ Date: _________

Personal Information:

1. Gender: i. Male ii. Female

2. Income level:

0 Income	Student/ Jobless	
less than 20,000	Low class	
20,000-50,000	Low	Middle class
50,000-100,000	High	
more than 100,000	High class	

3. Vehicle ownership: i. Bicycle ii. Motrocycle iii.Car iv. Others

4. Where do you live? ____

Trip Information:

5. Origin (Coming from):______________ Destination (Going to):________________

6. Trip phase: i. Access trip (going to board Metro) ii. Egress trip (Alighted from Metro)

6. Trip Purpose: i. Work ii. Education iii. Shopping iv. Entertainment v.Others

7. Do you usually use Metro bus? i. Daily ii. Once per week iii. Rarely

8. Trip Attributes

Attributes	Distance (km)	Time (minutes)	Cost (PKR)	Mode
From origin to Metro				
From Metor to destination				
In Metro (Name the terminals)			/	/

9. Assessment of existing feeder mode:

	Very good		Good		Fair		Bad		Very bad	
	Access	Egress	Access	Egress	Access	Egress	Access	Egress	Access	Egress
Service/ Route reliablity										
Travel time										
Cost/ fare										
Comfort										
Safety & Security										
Environmental aspects										

Willingness to pay for better service:

10. If the feeder services are more reliable and frequent, air-conditioned, and take less time than currently, would you be prepared to pay more for the service?

1. Yes 2. No

11. If yes, how much are you prepared to pay additionally for the same trip? ________________PKR

APPENDENDEX – II

QUESTIONNAIRE SHEET FOR THE SECOND FIELD SURVEY

(Conducted during March 2015)

WILLINGNESS TO USE METRO BUS

Surveyor Name: _______________ Location: ________________ Date: __________

Personal Information:

1. Gender: i. Male ii. Female

2. Income level:

0 Income	Student/ Jobless	
less than 20,000	Low class	
20,000-50,000	Low	Middle class
50,000-100,000	High	
more than 100,000	High class	

3. Vehicle ownership: i. Bicycle ii. Motrocycle iii.Car iv.Others

Trip Information:

4. Origin (living):___________________ Destination (workplace):__________________

5. Travel mode:

Main Mode		Total travel cost (PKR)	Total travel time (min)
Walk			
Public transport	Metro bus		
	Local bus		
	Paratransit		
Private vehicle	Motorcycle		
	Car		
Others			

*(*Feeder Services are designed to take passengers to the nearest transfer point of any mass transit system (metro bus) where they can catch the other service to take them to their destination)*

In case of Metro bus:

6. Trip Attributes

Attributes	Distance (km)	Time (minutes)	Cost (PKR)	Mode
From origin to Metro				
From Metor to destination				
In Metro (Name the				

7. Assessment of existing feeder mode:

	Very good		Good		Fair		Bad		Very bad	
	Access	Egress	Access	Egress	Access	Egress	Access	Egress	Access	Egress
Service/ Route reliablity										
Travel time										
Cost/ fare										
Comfort										
Safety & Security										
Environmental aspects										

Willingness to pay for better service:

8. If the feeder services are more reliable and frequent, air-conditioned, and take less time than currently, would you be prepared to pay more for the service?

1. Yes 2. No

9. If yes, how much are you prepared to pay additionally for the same trip? _______________PKR

In case of other than Metro bus:

10. Distance of Metro nearest station from (kms) Origin = Destination =

11. Will you prefer to use Metro bus, if provided with efficient Feeder service?

1. Yes 2. No

12. If 'yes', will you pay Rs. 60 for a complete one side trip?

(Feeder = Rs. 20, Metro bus = Rs. 20, Feeder = Rs. 20)

1. Yes 2. No, Don't change mode 3. More than Rs. 60 (how much) Rs._____