ANALYZING THE EFFECT OF TRANSIT STATION'S LOCATION ON WALKING ACCESSIBILITY

By

Muhammad Zaheer Khan

(2019-NUST-MS-TN-00000318326)

Department of Transportation Engineering

School of Civil and Environmental Engineering (SCEE)

National University of Sciences & Technology (NUST)

Islamabad, Pakistan

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Thesis supervisor: Dr. Muhammad Asif Khan

School of Civil & Environmental Engineering

National University of Sciences & Technology,

Islamabad, Pakistan

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Department of Transportation Engineering

National University of Sciences and Technology

Student Name: Muhammad Zaheer Khan Signature: ________________

Examination Committee:

a) Dr. Arshad Hussain Signature: ________________

(Assistant Professor, HOD Dept. of Transportation Engineering, SCEE, NUST)

b) Dr. Sameer Ud Din Signature: ________________

(Assistant Professor, Dept. of Transportation Engineering, SCEE, NUST)

Supervisor Name: Dr. Muhammad Asif Khan Signature: __________

Name of Dean/ HOD: Dr. Arshad Hussain Signature: __________

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DEDICATION

Dedicated to my exceptional father whose urge for acquiring higher education, to my loving mother whose comforting me through hard times and always believing in me and my adored siblings whose enormous persistent support and cooperation helped me attain this accomplishment.

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Unending glory to **Allah**, The Exalted, who granted me the primary inspiration and stamina all along to complete this humble work. This small contribution, if just and correct, is only a drop of appreciation for His Ocean of munificence.

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(Engr. Muhammad Zaheer Khan)

ABSTRACT

Transit-oriented development (TOD) is a need of the modern world. It has the potential to solve traffic related problems in compliance with sustainability. In this study the effect of transit station location, in an urban environment, on walking accessibility has been evaluated. The study has assessed the accessibility using a Ped-Shed/Pedestrian Catchment concept rather the circular buffer concept. The Ped-Shed/Pedestrian Catchment concept utilizes the path followed through the actual road network, unlike the circular buffer that relies on the radial path. This gives the accessible area around the station based on the actual road network conditions. The evaluation is based on two accessibility indicators as: Ideal Station Accessibility Index (ISAI) and Pedestrian Route Directness (PRD), to get an effect of station location on walking accessibility. The ISAI shows the accessible road density around the station while the PRD shows its walk efficiency. As a case study, we have selected the Rawalpindi-Islamabad bus rapid transit that is located in Pakistan. It is observed that ISAI and PRD have different values for stations in different environments. These values were analyzed for the effect of station location and activity types. It is concluded that accessibility indices have better values in locations having the dense spider-net type of road network than the grid-iron type network. The paucity of direct pedestrian routes and the presence of activities like an electricity grid station, army depot, major interchange, and large premises near the station breaks the continuity in the road network that badly affects walking accessibility.

Keywords: Transit Oriented Development, Accessibility, Pedestrian Catchment, Pedestrian Route Directness, Sustainability

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LIST OF ABBREVIATIONS

LRT	-	Light Rail Transit
HRT	-	Heavy Rail Transit
BRT	-	Bus Rapid Transit
ROW	-	Right Of Way
LRV	-	Light Rail Vehicles
MRT	-	Mass Rapid Transit
TOD	-	Transit Oriented Development
IEA	-	International Energy Agency
Mtoe	-	Mega Ton of Oil Equivalent
SUV	-	Sports Utility Vehicle
BMI	-	Body Mass Index
APTA	-	American Public Transportation Association
USA	-	United States of America
PRD	-	Pedestrian Route Directness
NESPAK	-	National Engineering Services Pakistan
PT	-	Public Transport
GIS	-	Geographic Information System

RF	-	Radio Frequency
MCA	-	Multi Criteria Analysis
MCE	-	Multi Criteria Evaluation
AHP	-	Analytical Hierarchical Process
O-D	-	Origin - Destination
CBD	-	Central Business District
DA	-	Dissemination Areas
ETM	-	Electronic Ticket Machine Data
GPS	-	Global Positioning System
PSO	-	Particle Swarm Optimization
GA	-	Genetic Algorithm
PCA	-	Pedestrian Catchment Area
TCQSM	-	Transit Capacity and Quality of Service Manual
TAZ	-	Traffic Analysis Zone
API	-	Application Programming Interface
ISAI	-	Ideal Stop Accessibility Index
ASAI	-	Actual Stop Accessibility Index

CHAPTER 1: INTRODUCTION

1.1 GENERAL

Urban public transportation comprises of systems that are widely used by the public at a cost of subsidized fare. It includes both transit and paratransit modes of services (Kim, 2009). Urban transit, mass transit or public transportation are transport modes of characteristics that operate on fixed routes and follow a fixed time table/schedule (Kim, 2009). This system includes bus, tram, light rail transit (LRT), rapid rail or heavy rail transit (HRT) and bus rapid transit (BRT) (Rinkesh, 2019). Irrespective of being served same purpose, they differ from each other in operational characteristics (such as capacity, station spacing, speed and right-of-way).

Walking is considered as a major mode of access for public transport. The Table 1-1 shows the importance of walking trips to transit stations represented in form of percentage of total access trips around the world. It reveals that the mode share of walk is quite high in the European, Australian, and American cities as compared to the Asian city, Bangkok. The lesser share of walk in Bangkok can be justified by considering the dominant mode, motorcycle taxi for accessing transit, which has the mode share of 30% (Chalermpong & Wibowo, 2007).

Generally, walk being a major mode of access to public transport is considered for planning to identify a station/stop location. The tendency to walk in an environment depends on socio-demographic, and travel behavior characteristics. Findings from the past studies revealed that those areas with more intersections, high density, and more interconnected streets result in increased walkability (Cervero et al., 2009) (Xiao et al., 2020).

Table 1-1: Mode share of walk in accessing transit services in different cities around the world

Location	Access trips to transit by walk mode (%)	Reference Study
Brisbane, Australia	96	(Burke & Brown, 2007)
Kristiansand, Norway	91	(Tennøy et al., 2022)
Oslo, Norway	90	(Tennøy et al., 2022)
USA	90	(Pucher et al., 2011)
Sydney , Australia	89	(Daniels & Mulley, 2013)
Stavanger, Norway	82	(Tennøy et al., 2022)
Madrid, Spain	80	(García-Palomares et al., 2013)
Hamar, Norway	80	(Tennøy et al., 2022)
San Francisco, USA	78	(Cervero, 2001)
Bangkok, Thailand	37	(Chalermpong & Wibowo, 2007)

On the other hand, areas that are less dense, destined O/D survey prefer car journey supported by spacious roadways and prevent walking (Cervero et al., 2009). Various studies have shown that socioeconomic factors (e.g. income, age and gender) are non-significant in adopting walking habits (Daniels & Mulley, 2013) (Kamruzzaman et al., 2016). Moreover, streets in the proximity of a transit station are found to be hotspots for walkers (Kamruzzaman et al., 2016), specially areas under the radius of 1 km from transit stations have been found as walk dominant (Cervero, 2001). Therefore the hotspot areas are best suited for such studies focusing on finding locations in urban areas for placing public transit stations that can attract number of users. This research applies methods to estimate walking accessibility to transit stations. The aim of this research is to investigate the effect station location in different urban areas on walking accessibility.

1.2 PROBLEM STATEMENT

The research done so far ignores the effect of station location on walking accessibility. Even if there exist some literature contributing towards the walking access to PT, they use simple proximity based methods (Foda & Osman, 2010). These methods either utilize the circular buffer concept or intersection count around the station.

Although, there are updated and more precise methods used in the literature but they have rarely been focused on finding the effect of station location in an urban environment on walking accessibility. More research is required that studies the effect of station location in urban environment on walking accessibility (Ibraeva et al., 2020). Our research tries to address this gap by using the method of actual pedestrian catchment and PRD test. The research considered Rawalpindi-Islamabad BRT as case study from Pakistan due to growing number of new transit projects and lack of research on its public transport system (Khan et al., 2018). Rawalpindi-Islamabad BRT service has been selected as the project area. This service spans across two cities of diverse nature, thus giving an opportunity to study the effect of station location on walking accessibility in more versatile environments.

1.3 RESEARCH OBJECTIVES

The "design" of built environment and the "distance" to transit influence the walkability in an urban setting (Alawadi et al., 2021). Walking accessibility to public transport closely corresponds to distance to stations/stops. Therefore, the spacing as well as spatial location significantly affect the accessibility to and walkability of stations/stops as they define the travel time involved (Foda & Osman, 2010). The aim of this research is to analyze the effect of station location in an urban environment on walking accessibility to it. The accessibility can be estimated in many ways but the thesis will focus on practical methods that rely more on actual street network variables. The objectives of this research work are to:

- Estimate the walking accessibility to transit stations based on actual street network.
- Evaluate the effect of station location in different urban environments on walking accessibility.

- Give recommendations on location of stations for future transit services.

1.4 SCOPE OF THE RESEARCH

As far as transportation is concerned, it is believed that roads cannot be built fast enough to keep up with the rising demand for them (Ewing & Cervero, 2010). That is why state departments throughout the world are turning to strategies for improved transport planning to meet the travel demand in a more sustainable way. To foster the urban and transport sustainability, transit oriented development (TOD) has been most successful since 1980s (Ibraeva et al., 2020). "TOD can be described as land use and transportation planning that makes cycling, walking, and transit use desirable by focusing development around public transport stations/stops" (Thomas & Bertolini, 2017). In TOD, it is not only the provision of transit service that is necessary; but planning for the accessibility to it is equally important.

As discussed in the previous sections that walk is a major mode of travel when it comes to accessing the transit. That's why it is very important to consider it while deciding the location of transit station. This research work, although, considers the BRT service but can be used for any transit service (bus, tram, light rail and heavy rail) while locating its station. The transit service can be accessed by many modes including the private cars, taxis, Uber/Careem, rented bike and even other transit modes. However, we have focused on walk only to foster the TOD. The selected radius of influence of walk for transit is 400 meters keeping in view the past literature. Therefore, street network inside this radius is studied only. The research work considers any street/road as walkable where presence of footpath, service roads and pedestrian movement is observed. The accessibility indices discussed in the methodology section are used to quantify the walkability of street network around the transit stations. A transit station may have highest ridership and lowest walking accessibility index value. This pertains to the fact that station can be highly accessible to the community through modes other than walk. In other words, the scope of this research is to find factors that can maximize only the walking accessibility for transit in an urban environment, and not the total accessibility to transit.

1.5 OVERVIEW OF STUDY APPROACH

The plan organized to achieve the research objectives successfully is discussed stepwise as under:

- Detailed literature review of the past research to establish methodology and data requirement.
- Selecting an appropriate methodology with regard to the data availability for estimation of accessibility.
- Addressing the limitations in the methodology through additional measures to improve the walking accessibility.
- Collecting street data from various sources, marking station locations and correcting the street data where deemed necessary.
- Running analysis in Geographic Information System (GIS) software to find the most suitable locations and the urban environment features that can maximize the walking accessibility to transit.
- At the end, enlisting limitations of this study and providing recommendations for future research.

1.6 ORGANIZATION OF THE THESIS REPORT

This thesis report provides a background that necessitates the need for the research on the selected topic in Chapter 1. Literature review is presented in Chapter 2 that covers the past research on walk, and the methods used for estimation of walking accessibility. Different methods have been discussed stating their limitations as well. Chapter 3 provided a detailed plan of methodology to attain the objectives set in this study. A case study is presented that shows the project area and its dimensions. A study framework has also been attached at the end of this chapter. Chapter 4 presents the results and discussion section based on the findings from the proposed case study of Rawalpindi-Islmabad BRT service. Chapter 5 gives conclusions from the study and provides recommendations for the future research.

CHAPTER 2: LITERATION REVIEW

Walking is a major of mode of non-motorized transport in our daily lives (Burke & Brown, 2007). We access different amenities through walking. Such important mode of transport is not only a way of access to different amenities and other transport modes, but is also a healthy physical activity. Because of these utilities, the walking mode is studied by many researchers of transportation engineering and other fields.

This chapter allows an extensive examination of literature about each component of our research question – how the location of transit station in an urban environment can affect the walking accessibility to it? This chapter starts with the introduction of important terminologies related to public transit services and impact of physical built environment characteristics on walkability in an area. The chapter also discusses that how walking access is related to transit use. At the end, accessibility evaluation methods in terms of walking access to public transit services used by past researchers had been presented.

2.1 IMPORTANT TERMINOLOGIES

Urban public transportation has two main features: (i) open to public (ii) at a cost of an established fee/fare. Urban public transportation includes both transit and paratransit since both are available for public use and has established fares/rates. However, it is customary to identify only transit as public transportation (Kim, 2009). Urban transit, mass transit or public transportation, additionally, has two features: (i) it operates on fixed routes and (ii) follows a time schedule (Kim, 2009). Its classification is depicted in Figure 2-1. This system includes bus, tram, light rail transit (LRT), Rapid rail or heavy rail transit (HRT) and bus rapid transit (BRT) (Rinkesh, 2019).

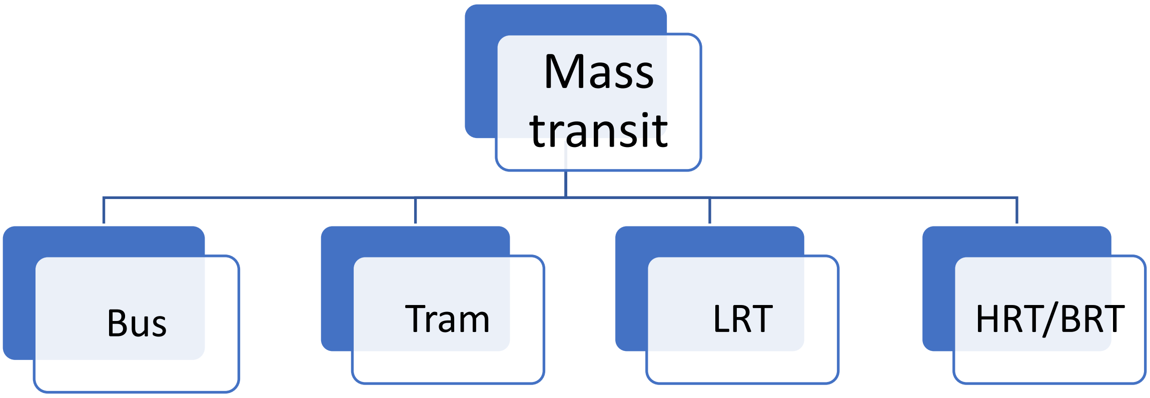

Figure 2-1 Classification of mass transit or transit

These modes, although serving the same purpose, differ from each other in operational characteristics that are shown in

Table 2-1. The visual aids of each modes has been presented in Figure 2-2. The figure can be seen to portray the differences shown in

Table 2-1 very accurately. It shows the difference between ROW, operational environment and vehicle mode in use for all the transit types.

Table 2-1 Difference between modes of transit

Bus	Tram	Light Rail	Heavy Rail / BRT
- Less passengers (Government of the Netherlands, 2012)	- High demand (Government of the Netherlands, 2012)	- Capacity < HRT	- High capacity
- Better Speed (Rinkesh, 2019)	- Slow Speed (Guarnieri, 2020)	- Speed > Tram	- High speeds
- No defined path	- Defined Path	- Defined path	- Separate ROW (Wikipedia, 2022c)
- No exclusive ROW	- Segmented ROW	- Separate ROW	- ROW Grade Separated (Wikipedia, 2022a)
		- ROW not grade-separated (Wikipedia, 2022b)	

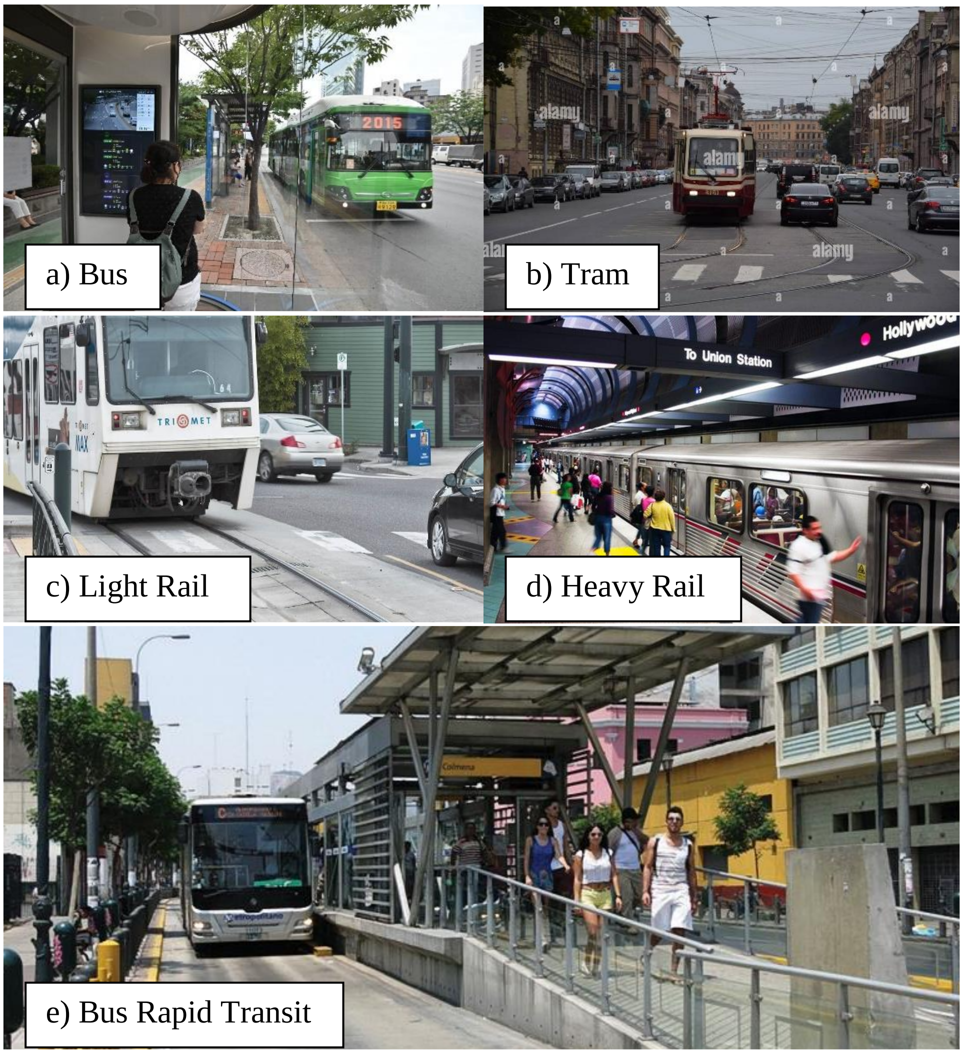

Figure 2-2 Different transit mode types.

Source: (Rinkesh, 2019) (Guarnieri, 2020) (Wikipedia, 2022b) (Wikipedia, 2022c) (Wikipedia, 2022a)

2.2 WALK AND BUILT ENVIRONMENT

(Kamruzzaman et al., 2016) correlated the walking distance in an urban environment to the individual characteristics and built environment attributes e.g. intersection density, proximity to a PT (Public Transport) station, land use mix, street density. The study found that 10 minutes' walk to transport facilities is considered as good access while walk time above 10 minutes is considered as poor access. Areas with more intersections, high density, proximity to a station and more interconnected streets resulted in more walkers. Brisbane, Australia, was used as the study area.

(Cervero et al., 2009) analyzed the dependence of physical activity (walking and cycling) on built environemnt and socioeconomic charateristics, and policy variables using multi stage stratified data sampling. The sociodemgraphic data of the individuals was taken from the government survey. Physical activity was measured in minutes per weekday as non-motorized travel. Bogota Island, Colombia, is selected as study area. The study results revealed that dense and mix land use are good promoters of walk where as low density and spacious roadways areas that are car oriented prevent walk. Additionally, it was found that walking and cycling trips under 5-mile length are promoted by the street connectivity, density, and land use. Distance to parks and presence of public transit services also increases the activity level.

(Xiao et al., 2020) correlated the number of walking trips in an urban environment to its socio-demographic characteristics. The Probit model was used to identify the trip as walk based and Xiamen Travel Survey,China (2015) was utilized for data acquisition. It was found that walking is positively correlated with the intersection density, housing density, land use mix, transport access, and negatively correlated with distance to market.

(Naharudin et al., 2017) made use of a mobile application to collect larger and more accurate data of pedestrians in short time and find the effect of built environment objects and components on walking intensity. Data was collected using GIS (Geographical Information System) and RF (Radio Frequency) signal technology. The data included information about the travel routes selected and the travel speed and direction. MCA (Multi Criteria Analysis) was done and fifty train riders were interviewed to get the weightages of the MCA variables. The MCA score and the actual pedestrian counts were in close agreement. The results show that the more preferred features, like building's shade and food/beverage vendors, promote walking frequency and trip lengths. It was also found that it is not the total number of built environment features that effect the walking activity but rather the features that are more preffered by the residing community.

(Taleai & Taheri Amiri, 2017) tried to quantify the walkability of streets through a walking index using a method that is based on GIS, MCA and individual's opinion/survey. Analytical hierarchical process (AHP) was used to find the weightages of MCA variables for the walking index calculation. Kappa coefficient was used to check the agreement between expert and non-expert opinions of the survey, which came out to be moderate agreement. In the end, the pedestrian count from google map street images were checked against the walk index and a strong relation between them was observed.

2.3 WALKING FOR PUBLIC TRANSPORT

(Burke & Brown, 2007) aimed at finding the pedestrian zones around public transport stations in an urban environment. The study used "Easyfit" software to spatially distribute the person trips, which were obtained from Queensland travel survey, Australia - A survey that constains the walking data corresponding to the multimodal trips. The data distribution resulted in high frequency zones of pedestrian activity around the transit stations. In the end these zones were further analyzed to find that people walk to transit services for more than 2.3 km and over 28 minutes.

(Chalermpong & Wibowo, 2007) conducted a study that focused on evaluating the pattern of access trips to stations and the factors affecting the propensity to walk for public transport. Individual survey was conducted on the stations where most commute trips originate and data about access mode, time, cost, distance, number of transfers and socioeconomic characteristics was collected. The walking behavior was presented by binary logit model. Walk dominant areas around transit stations were traced as circles, which are known as catchment areas. The catchment areas were found out to be 2000-meter radius around the station. It was found that most of the walkers are low income, young people having low car ownership, and occasionally walking more than 1 km distance.

(Daniels & Mulley, 2013) determined the effect of demographic factors, socioeconomic factors and trips characteristics (time, day of the week etc.) on trip between origin and transit station. The study made use of Sydney household travel survey, which is a one-day trip diary of the travel in the metropolitan areas and comprises of the face-to-face interviews. The ArcGIS was used to estimate the distance from walking time. Regression was done to relate trip distance from home to station/stop to the above discussed parameters of interest. It was found that socioeconomic factors and trips characteristics are non-significant in explaining walk for public transport. The research shows that once the decision of walking is made, it is the mode of public transport that influences the distance walked and that depends on the supply of the mode of transportation.

(Cervero, 2001) studied the public transit stations in terms of dominance of different modes of access. Survey data of onboard 35000 passengers was collected at different transit stations regarding the distance walked and mode of access taken. GIS was used to plot these distances in the form of a straight lines emerging from stations. These lines were then classified according to their respective modes of access obtaining the high intensity zone of each in the form of concentric circles. The results revealed that 5/8 mile radius was walking dominant area around the transit stations, 5/8 to 1 mile was transit dominant and beyond 1 mile was car dominant in terms of mode of access. The land use density and the intersection density were found significant in promoting walk.

2.4 WALKING ACCESSIBILITY TO PUBLIC TRANSIT SERVICES – A SUMMARY OF PAST RESEARCH EFFORTS

Walking accessibility towards transit station has been approached by most of the research literature using conventional methods (Foda & Osman, 2010). These conventional methods use circular buffer concept that works on the basis of proximity ignoring the practical road network and other infrastructure condition. Better and updated methods need to be employed to ascertain the location of the station for improved walking access. Limitted research, if any, is available in the literature that use advanced methods of accessibility evaluation but they are directed at problems other than station location (Ibraeva et al., 2020).

(Salvo & Sabatini, 2005) incorporated different characteristics of urban environment in the evaluation of walking cost around transit stations in non-monetrary terms using a GIS software. As a result, a network of low cost walk paths in the vicinity of transit stations is obtained. The street urban environment characteristics that were used in evaluating the non-monetary cost of walk around transit station includes the data of shop types, activity levels, population density and street's obstruction around the transit stations. The study proposes that accessibility can be improved around transit stations by placing new stations in such locations that minimize the cost of walking.

(Ziari et al., 2007) used the total travel time for finding the optimum walking accessibility measures. The method adopted consists of microscopic level data collection about the walk time, waiting time, distance between transit stations and corresponding time, and acceleration/deceleration times. The author has come up with an equation that relate the total travel time to the described variables. Putting the average total travel time and distance of the journey between two points in the equation, the walking access buffer distance can be calculated. In other words, he related the accessibility to the systems operational characteristics. He found that the better operational characteristics result in better accessibility due to increased utility/attraction of the system.

(Alam et al., 2010) used the gravity model to estimate the walking accessibility around the stations. The authors used survey data to estimate friction coefficient in the gravity model. The production and attraction variables of gravity model were based on population density, job density and percentage of population living in central business districts (CBD) or downtowns. He proved that his method produced more realistic accessibility values than traditional methods – that depend on simple circular buffer of ¼ mile radius around the station. However, the method was analytical in nature and ignored the actual road topology inside the study area.

(Foda & Osman, 2010) estimated the walking accessibility around the transit stations more accurately by taking the actual street network into consideration rather than relying on simple circular buffer. A digitized map of street network was used that had station locations marked on it, and network analysis feature of QGIS application was executed to obtain the actual pedestrian catchment areas around the stations. Accessibility indices were used to evaluate walking accessibility inside these catchments and it was found that simple circular buffer method overestimates the accessibility as compared to pedestrian catchment (Ped-shed) by 50 percent.

(Kalaanidhi & Gunasekaran, 2013) used composite impedance gravity measure to assess the walking accessibility to transit. The authors used the in-vehicle, out-of-vehicle times and costs, and cost of parking for estimating accessibility. Transit ridership data was also collected and then compared with the accessibility values from the gravity model. It was found that the waiting time is more significant in affecting ridership than the out-of-vehicle cost.

(Eboli et al., 2014) used the TCQSM (Transit Capacity and Quality of Service Manual) method for calibrating the circular radius using factors based on actual road network characteristics to obtain effective radius. This method improved the accuracy in calculating walking accessibility. The results showed that street connectivity, gradient and population have greater influence on the accessibility.

(Vale, 2015) improved the original TOD classification model of (Bertolini, 1996) by incorporating the pedestrian catchment method concept with 700 meter favorable walking distance. This shows the importance of pedestrian catchment method in dealing with older issues more practically. (Bertolini, 1996) did a cross sectional study to analyze the location of transit stations, particularly heavy rails, in the surrounding environment and found that transit stations are places of diverse activities that are affected by global and local dynamics. The research also suggested that transit stations should be given due consideration and treated both as a node and a place while defining a redevelopment strategy in the surrounding landuse.

(Pafka & Dovey, 2017) estimated the accessibility to services inside the pedestrian catchments from transit station. Authors used area-weighted average perimeter and catchment interfaces, a measure based on area and perimeter of blocks within a catchment area. These measures takes both street width and block size into consideration. This way a clear depiction of “what is actually accessed” is made, unlike catchment area or ped-shed method. The study found that short blocks relatively performed well. However, the study also found that if the frequency and intensity of short blocks increases, then they impede the walking due to more pedestrian crossings that act as hurdles.

(Sun et al., 2018) studied the competitiveness of public transport and car in Shenzhen city by calculating travel time ratio of PT and car. This ratio was a time-based analogy to Pedestrian Route Directness test, which is distance based. The ArcGIS space analysis tool was used to know the accessibility based on the maximum acceptable walking time of passengers. The travel time ratio of car to PT is calculated at the end. The study also established that the value of the travel time ratio below 1.5 shows an efficient PT that is competitive to the private car mode.

(Sarker et al., 2020) calculated average accessibility buffer radius from intercept survey method on stations of different public transport modes. ANOVA and t-test methods were used to get the non-normal distribution of walking distance/time to the train and bus stations.

Dependent variable used in the study was actual walking time to station and independent variables were trip purpose, mode, location, car ownership, origin-destination, and socioeconomic characteristics. It was found that the age and profession has no correlation with the walking distance. The high urban density gives smaller catchment area around the stations and vice versa. People walk longer to the train station than to the bus or tram station due to higher reliability of train. Walker prefer shortest and direct possible route, considering the characteristics of route.

(Bree et al., 2020) used gravity-based accessibility model to predict the transit ridership at different stations. The tap card system data of the bus stations is used as ridership data. The study divides the research area into different zones and then find the percent of zone intersected with different stations' buffers. Then the tap card data of each station is distributed among the zones with respect to percent intersection with zones. In the end the summation of these tap card data for a zone is termed as the accessibility of the zone. The author finds it very accurate to estimate the accessibility in this way. However, this study does not consider any verification whether the distribution of ridership made is valid in actual or not. But, the accessibility calculated was found to be much better than circular buffer method.

(Shatnawi et al., 2020) conducted a study to optimize the location of bus stops using ArcGIS, Particle Swarm Optimization (PSO) and Genetic Algorithm (GA). The results of all three tools identified the redundant stations, which can be eliminated to improve operational conditions and hence reduce the travel time. In most of scenarios, the number of bus stops was reduced. The presence of irregularly placed stations worsended the operational condition so much that they reduced the walking radius from 2000 meters to just 400 meters.

(Alawadi et al., 2021) examined the contribution of alleyways in enhancing the walk efficiency of BRT stations' surrounding in Dubai. These stations were selected to reflect the varying typologies of street network designs and alleyways systems around each station. The different street network system represents the urban setting in different eras of development. Pedestrian Route Directness test (PRD) and the actual buffer polygon were used on the street network of the area. Pedestrian connectivity in this study measures both the distance and the directness of pedestrian routes. Distance is computed using the concept of pedestrian catchment areas (PCAs), while directness is measured using the concept of pedestrian route directness (PRD). The results say that the modern setting has low rate of passing the PRD while the old organic phase land use has higher rate due to good interconnectivity and more density of streets and alleyways.

The research done so far ignores the effect of station location on walking accessibility. Other limitations in the past research have been listed in a table provided in Appendix A. More research is required that studies the effect of station location in urban environment on walking accessibility (Ibraeva et al., 2020). Our research tries to address this gap by using the method of actual pedestrian catchment and PRD test. This study considered Rawalpindi-Islamabad BRT in Pakistan as a case study area due to number of new BRT projects in the country (Shiki & Khan, 2018).

CHAPTER 3: RESEARCH METHODOLOGY

Accessibility is treated differently by the scientists of different fields. Despite the increasing volume of research on accessibility, its general meaning is still unclear up to some extent because of no clear definition. Hansen first defined accessibility as the "number of opportunities available within certain level of distance or time" (Alam et al., 2010). In this way, it is the ease and convenience of access to different opportunities while having different mode choices of travel.

In this chapter the methodology to estimate the walking accessibility is discussed. The use of pedestrian cathments or ped-sheds is justified. Towards the end, the Pedestrian Route Directness (PRD) test and its role in addressing the shortcomings in the ped-shed method is explained. The chapter also gives details about the calculations and the data requirements.

3.1 CONCEPT OF PED-SHED

In most of the past research, circular buffer concept has been followed to assess accessibility to transit stations by walk mode (Salvo & Sabatini, 2005). This method does not take into account the real distribution of population and corresponding road network around the station resulting an overestimated accessibility to BRT station(Foda & Osman, 2010; Salvo & Sabatini, 2005). Since, this method assume that people can access the station from anywhere within the buffer ring and ignores the actual topology of the pedestrian pathways surrounding the stops, therefore estimated accessibility results may not reflect actual results.

A limited road network and its connectivity within the buffer to access BRT station may not allow riders to access BRT station directly. To overcome this limitation, a network constrained approach can be adopted assuming a walking threshold up to 400m from BRT station. In literature, this area is known by the names of Ped-shed, pedestrian catchment and actual buffer area (Ibraeva et al., 2020). To find it, the 400 m distance will be measured along the road network in all directions instead of using a circular buffer. The actual-distance-based buffer in all directions from the station can be estimated using a GIS application after modeling pedestrians' walkways along with stations' locations. Using an inbuilt tool of Network Analysis in GIS application, 400m fragments of all the roads surrounding the station were identified. Connecting the ends of these roads, established the Ped-shed around the station. Figure 3-1 shows the difference between circular buffer and actual accessible area called Ped-Shed.

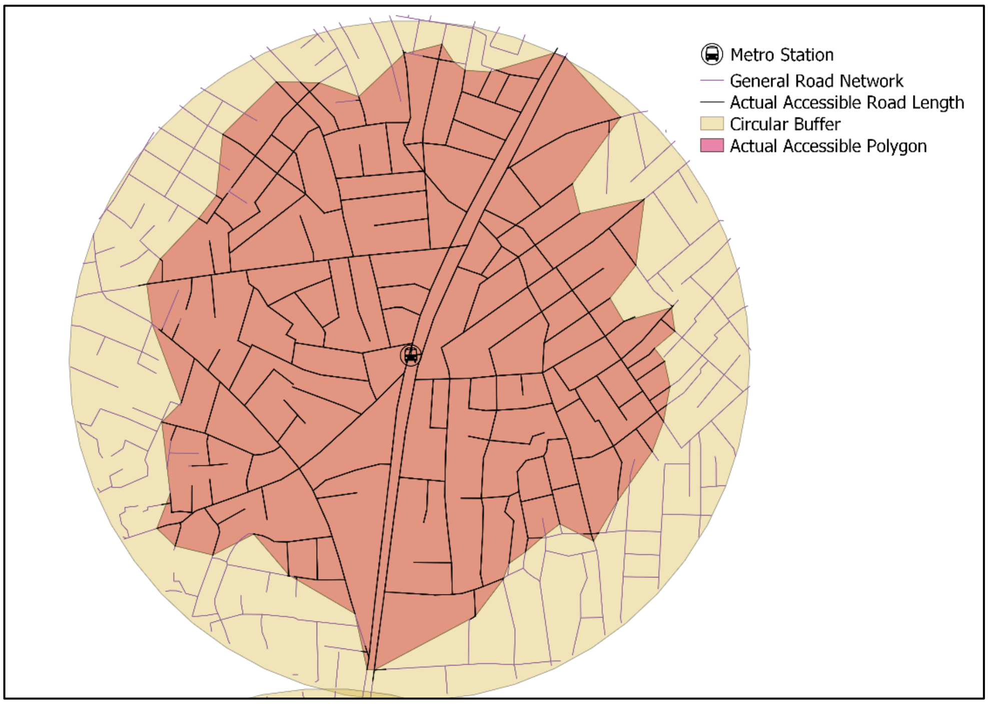

Figure 3-1 Difference between simple circular buffer and Ped-shed around a transit station

3.2 IDEAL STOP ACCESSIBILITY INDEX (ISAI)

In order to quantify the walkability inside the ped-shed some parameters are required. The parameters that have been selected are road density and road connectivity inside the ped-shed. Connectivity is discussed in the next section. The road density in this study is represented by Ideal Station Accessibility Index (ISAI) as considered by the past research (Alawadi et al., 2021; Foda & Osman, 2010). This index shows the accessibility in terms of the road length inside the ped-shed that can be walked to reach the public transit station, also known as Metric Reach (MR). Unlike other variables, ISAI considers the total reachable road length as well as considers the area of the circular buffer allowing the comparison of different radii and study zones (Ibraeva et al., 2020). ISAI is calculated as:

$$ISAI = \frac{L_A}{A_C}$$

Where, (see Figure 3-1)

- ISAI = Ideal Stop Accessibility Index
- L_A = Actual Accessible Road Length inside the Ped − shed
- A_C = Area of the Circular Buffer

3.3 PEDESTRIAN ROUTE DIRECTNESS (PRD) TEST FOR STREET EFFICIENCY

The accessibility index value shows the accessible street density of the area and does not provide the complete knowledge about the spatial distribution with respect to efficiency of roads around the public transit stations. Rather, it estimates the intensity of road supply around the station. In other words, the road network around a station may be very dense (more intensive road supply) but due to presence of cul-de-sacs and obstructions, the street connectivity can be very low. Denser road network result in very high ISAI value but due to limited street connectivity, actual walkability to access station would be low. This limitation makes ISAI method inefficient.

To account for this limitation, the pedestrian route directness test (PRD Test) is applied to the station locality within the adequate walking distance. The use of this test has been favored by Dubai Urban Street Design Manual (Alawadi et al., 2021). This design manual recommends a maximum value of PRD as 1.5 for good and efficient street network. The value of PRD indicates the ratio of actual walking distance between two points to the straight crow-fly displacement also known as Euclidean distance, as shown in Figure 3-2. This value has minimum value of “1” and indicates the straight radial path from station to point of interest. The formulation to estimate PRD values is given below:

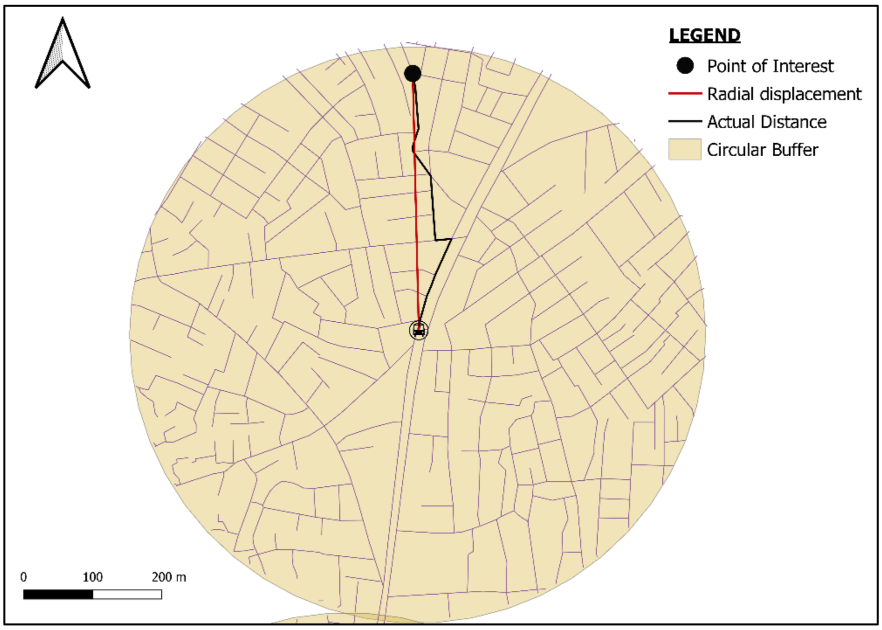

Figure 3-2 PRD: Ratio of actual walking distance to radial displacement

$$PRD = \frac{L}{L_R}$$

Where,

- PRD = Pedestrian Route Directness
- L = Length of actual road from station to point of interest
- L_R = Length of theoretical radial road from station to point of interest

For this study, we have calculated the PRD value for each station by selecting points randomly at a distance of 200 meters and 400 meters from stations and then taking their average.

3.4 DATA

The data for the research is taken from online sources. The street network is acquired from online OSM (Open Street Map) libraries. The road network map is imported into QGIS application. The station locations are marked on the map from the Google Earth's coordinates. The map is adjusted according to the road network of the Google's Satellite and Google's Roads Maps. The adjustments include solving the network topology errors such as the stations' entry and exit point connections to the street network and correcting the pedestrian network in the station vicinity. The data acquisition has been shown in Appendix B. Direct connections of major highways to stations is allowed only where the pedestrian facilities are provided or where noticeable pedestrian activities are observed. The definition of walkable streets is depicted in Appendix C.

The buffer radius around the station has been finalized from the research literature. Research states that 1000-meter distance around the public transit station is pedestrian dominated in terms of mode of access (Cervero, 2001). Of the total trips, 34 percent are walk trips that lies within 2 kilometers distance (Chalermpong & Wibowo, 2007; Daniels & Mulley, 2013). However, most researchers use radius of 400 to 600 meters as walking preferable area around transit station considering 1.3 m/s average walking speed and 5 to 7 minutes of walk on each access and egress (Foda & Osman, 2010). The exact figure depends upon the age, environment, and weather protection (Pafka & Dovey, 2017). For Islamabad, having long summers, 400 meters distance is considered in this study.

3.5 CASE STUDY

The Rawalpindi-Islamabad Bus Rapid Transit (Rawalpindi-Islamabad BRT) is a public transit service in twin cities of Pakistan. The first phase of this project, shown in Figure 3-3, is taken as a case study that was first operated in 2015. The service extends over 22.5 km stretch from Pak-Secretariat Islamabad to Rawalpindi Saddar and has 24 stations. Rawalpindi has 11 stations and the entire 8.6 km route is elevated. The rest of 13 stations are located in Islamabad over the length of 13.9 km. The local street network in both cities is different from each other. In Islamabad, it is grid-iron pattern (Capital Development Authority Islamabad, 2012) and in Rawalpindi, it is closer to spider-net pattern. The project has been selected because of the diverse nature of two cities giving an opportunity to study the effect of station location on walking accessibility in more versatile environments.

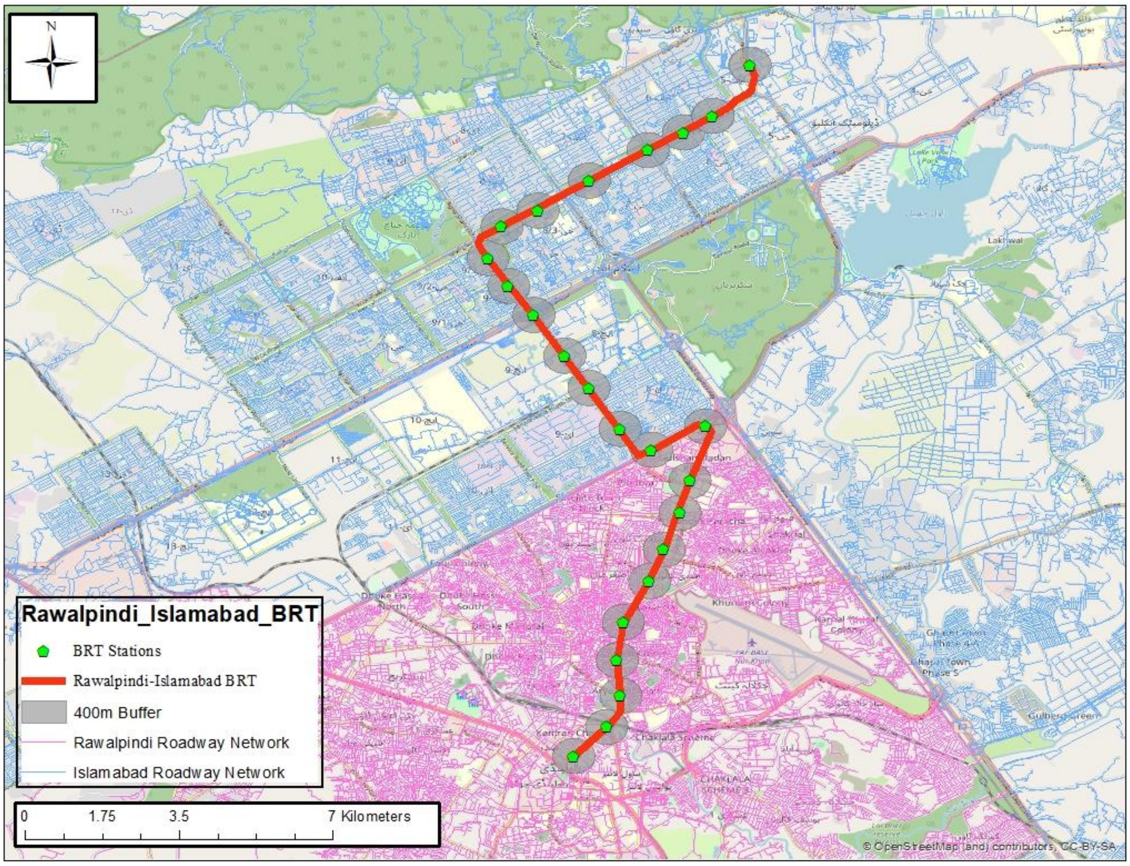

Figure 3-3 Map showing the Route of Rawalpindi-Islamabad BRT phase 1

We cannot escape the truth that this project is one of its kind in the both cities. In 2012, there were over one million trips taking place within Islamabad every day including half million trips to and from Rawalpindi of which public transport's mode share was 35 percent (Capital Development Authority Islamabad, 2012). The then population growth rate was 4% (Zia, 2017). Using this growth rate the trips taking place between two cities can roughly be estimated as 0.75 million as of 2022. Feasibility study conducted by M/S NESPAK predicted ridership of 139000 per day which was found later to be 125000 (Zia, 2017). The final methodology is depicted below.

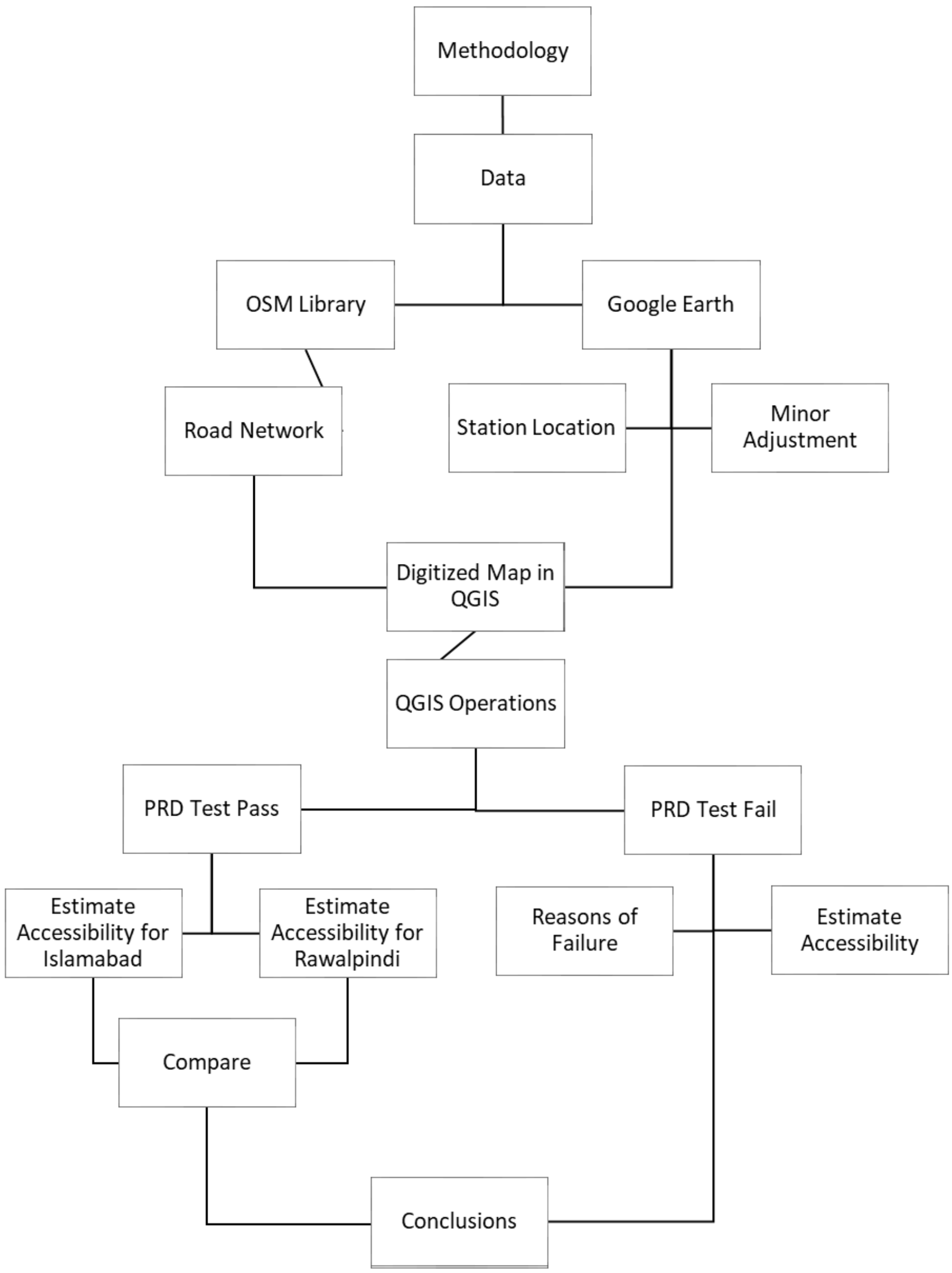

Figure 3-4 Methodology framework

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 GENERAL

Results have been presented descriptively in Table 4-1. The table shows values of the Ideal Stop Accessibility Index (ISAI) for all the stations. The table has been divided into two parts for stations in Islamabad and Rawalpindi. The Pedestrian Route Directness (PRD) values have also been shown with each station.

These results have been calculated according to the methodology explained in the previous sections. The buffer radius and actual walking distance is taken as 400 meters.

The results will be categorized and explained further in the coming sections.

Table 4-1 Calculations for all stations

Station Number	Station Name	Road Length in Circular Buffer(km)	Road Length in Actual Buffer (km)	Ideal Stop Accessibility Index (ISAI) (km/km2)	Average Pedestrian Route Directness (PRD) (km/km)
		Islamabad			
1	Pak Secretariate	10.07	5.97	11.88	1.41
2	Parade Ground	14.61	7.43	14.79	1.42
3	Shaheed e Millat	15.04	10.07	20.04	1.28
4	7th Avenue	16.83	8.19	16.30	2.21
5	Stock Exchange	14.76	5.79	11.52	2.14
6	PIMS Hospital	12.59	4.08	8.12	1.98
7	Katchari Chowk	10.06	5.67	11.29	1.26
8	Ibn e Sina	12.24	7.12	14.17	1.36
9	Chaman	14.06	9.53	18.97	1.29
10	Kashmir Highway	16.19	3.83	7.62	3.50
11	Faiz Ahmad Faiz	9.72	5.70	11.35	1.71
12	Khayaban e Johar	8.55	4.99	9.93	2.23
13	Potohar	15.22	8.73	17.38	1.48

		Rawalpindi			
14	IJP	10.23	4.12	8.20	2.85
15	Faizabad	13.85	5.68	11.31	1.58
16	Shamsabad	9.40	6.77	13.48	1.24
17	6th Road	12.11	7.35	14.63	1.37
18	Rehmanabad	12.93	6.05	12.04	1.67
19	Chandni Chowk	14.40	6.86	13.65	1.72
20	Waris Khan	21.39	13.50	26.87	1.31
21	Committee Chowk	18.95	11.40	22.69	1.31
22	Liaquat Bagh	12.53	7.27	14.47	1.47
23	Mareer	7.63	3.60	7.17	1.83
24	Saddar	9.80	6.00	11.94	1.36

4.2 STREET NETWORK OF ISLAMABAD

The graph showing the ISAI and PRD values of the stations in Islamabad that have passed PRD test (PRD less than 1.5) is presented in Figure 4-1. The Stations failing the PRD test have been filtered out. The figure also shows the corresponding street network configuration of each station. The graph has the stations arranged/sorted with respect to decreasing values of ISAI. The street network visuals in graph helps in understanding the values of indices more clearly with respect to the street network configuration.

Figure 4-1 shows that the station “Chaman” has highest value of ISAI and “Katchari Chowk” has the least value. The street configuration changes from dense and looping structure at left to network having more dead ends at the right. This follows the decreasing trend of ISAI value from left to right showing that the absence of looping in the network and less density badly influence the accessibility. Moreover, it can be said that the looping in the road network itself is due to closely spaced residential and commercial activities. Nevertheless, looping can result into too many pedestrian crossings, which start acting as hurdles at some point (Pafka & Dovey, 2017). However, it is certain that walking accessibility values are higher in dense and looping street configuration.

The main thoroughfares in the street network have been used in the analysis where there is the presence of footpaths on them. One thing should be kept in mind that there are high-rise buildings (3 – 15 storey) near the stations of “Shaheed e Millat” and “Parade Ground”. So, a single road serves the floor area of multiple storeys unlike the case of residential or single storey buildings. If we consider the single road multiple times for each storey of these high-rise buildings, the ISAI value will increase noticeably. This is one shortcoming of the method and needs to be addressed through integrating another tool/parameter with it. But, the station location having high rise multi-storey buildings in vicinity can provide more number of people or walkers for small ground area.

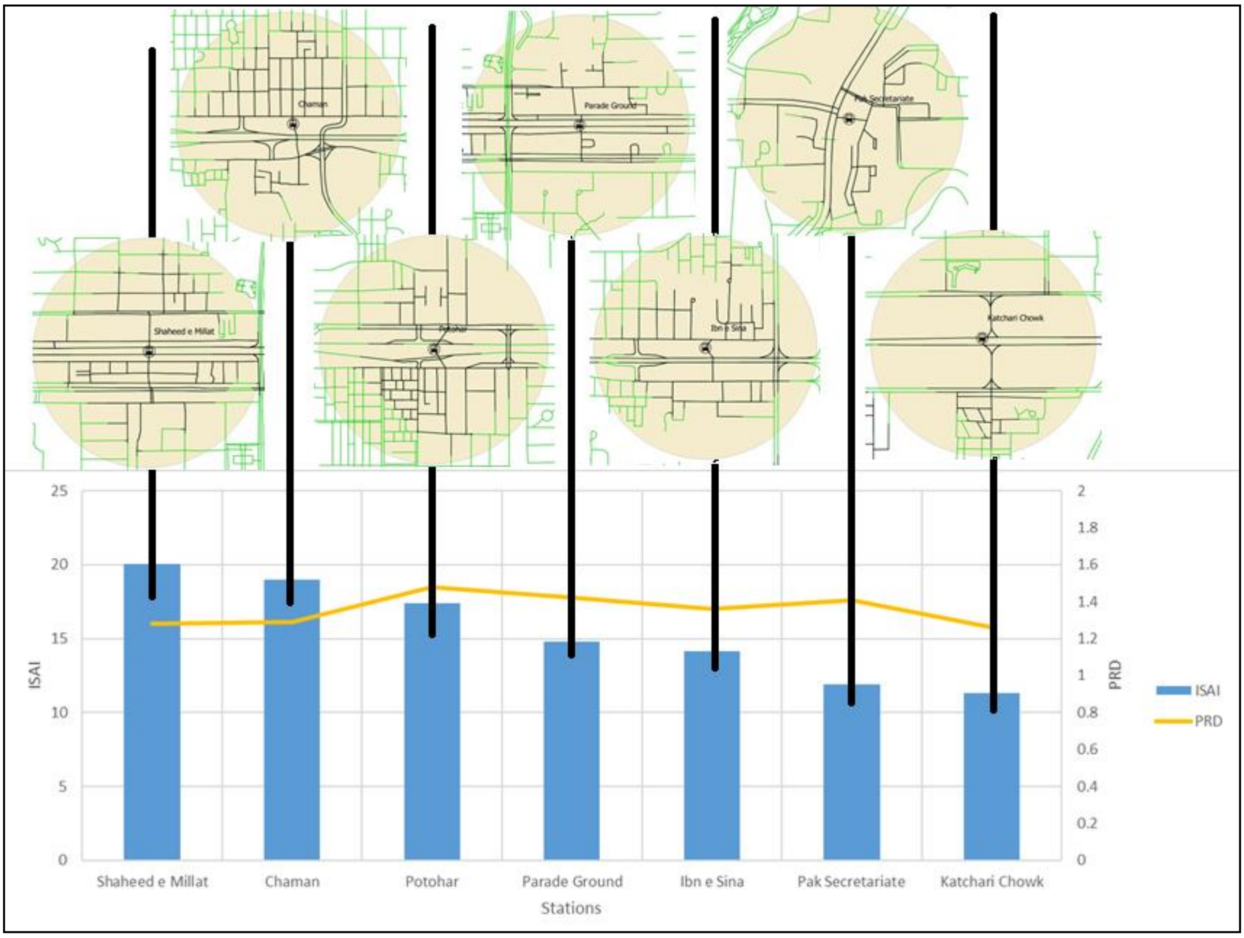

Figure 4-1 Index values for stations passing PRD test in Islamabad

4.3 STREET NETWORK OF RAWALPINDI

The results have been shown in the Figure 4-2 for Rawalpindi city in a similar way as for Islamabad. The figure shows only those stations that have passed the PRD test (PRD less than 1.5). The Stations failing the PRD test have been filtered out. As for Islamabad, the graph has the stations arranged/sorted with respect to decreasing values of ISAI from left to right.

The Figure 4-2 shows that the station “Waris Khan” has highest value of ISAI and “Saddar” has the least value. The street configuration changes from very dense and radial type structure at left (at “Waris Khan” and “Committee Chowk”) to network having more dead ends and grid type structure at the right. This follows the decreasing trend of ISAI value from left to right showing that dense radial/spider-net type network configuration like "Waris Khan" is likely to be more accessible than loose grid type and dead ended configuration.

Further, the "6th Road" station has high number of commercial activities on service roads and the presence of pedestrians on roads. It has grade separation for major traffic, U-turns and pedestrian crossings. This environment depicts the concept of shared space more closely, integrating the pedestrian and vehicles to use the road simultaneously in an agreement. That is why direct access has been given from stations to the roads. Owing to that, it has more ISAI value even though the network density is less as we move away from station. This concludes to the fact that station location in environments that closely relates to shared space is likely to promote walk for transport. Same can be said for "Shamsabad" station.

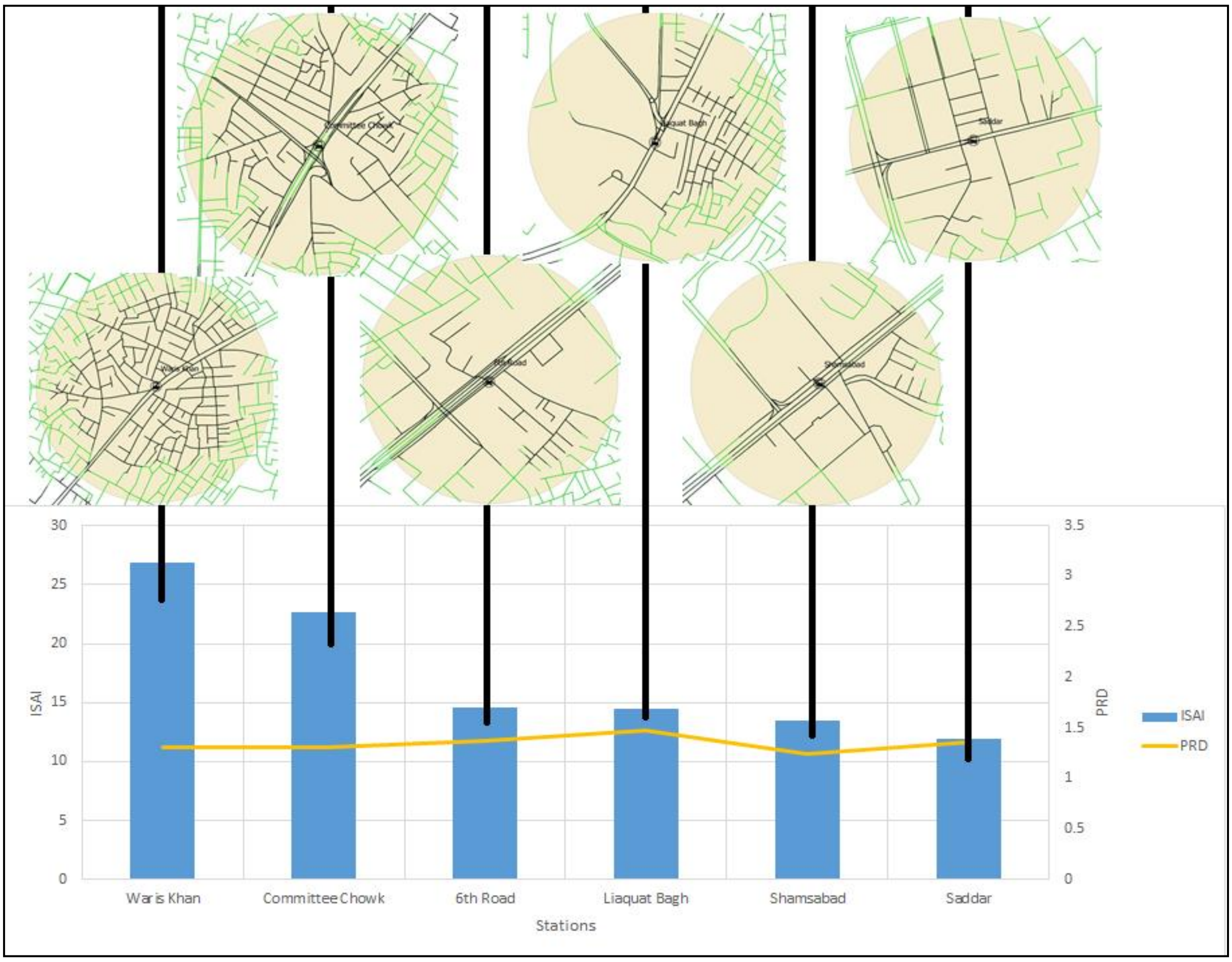

Figure 4-2 Index values for stations passing PRD test in Rawalpindi

4.4 STATIONS FAILING PRD TEST

Figure 4-3 and Figure 4-4 shows the stations of Islamabad and Rawalpindi, which have failed PRD test, respectively. In these figures, the stations have been arranged/sorted with respect to decreasing value of ISAI from left to right.

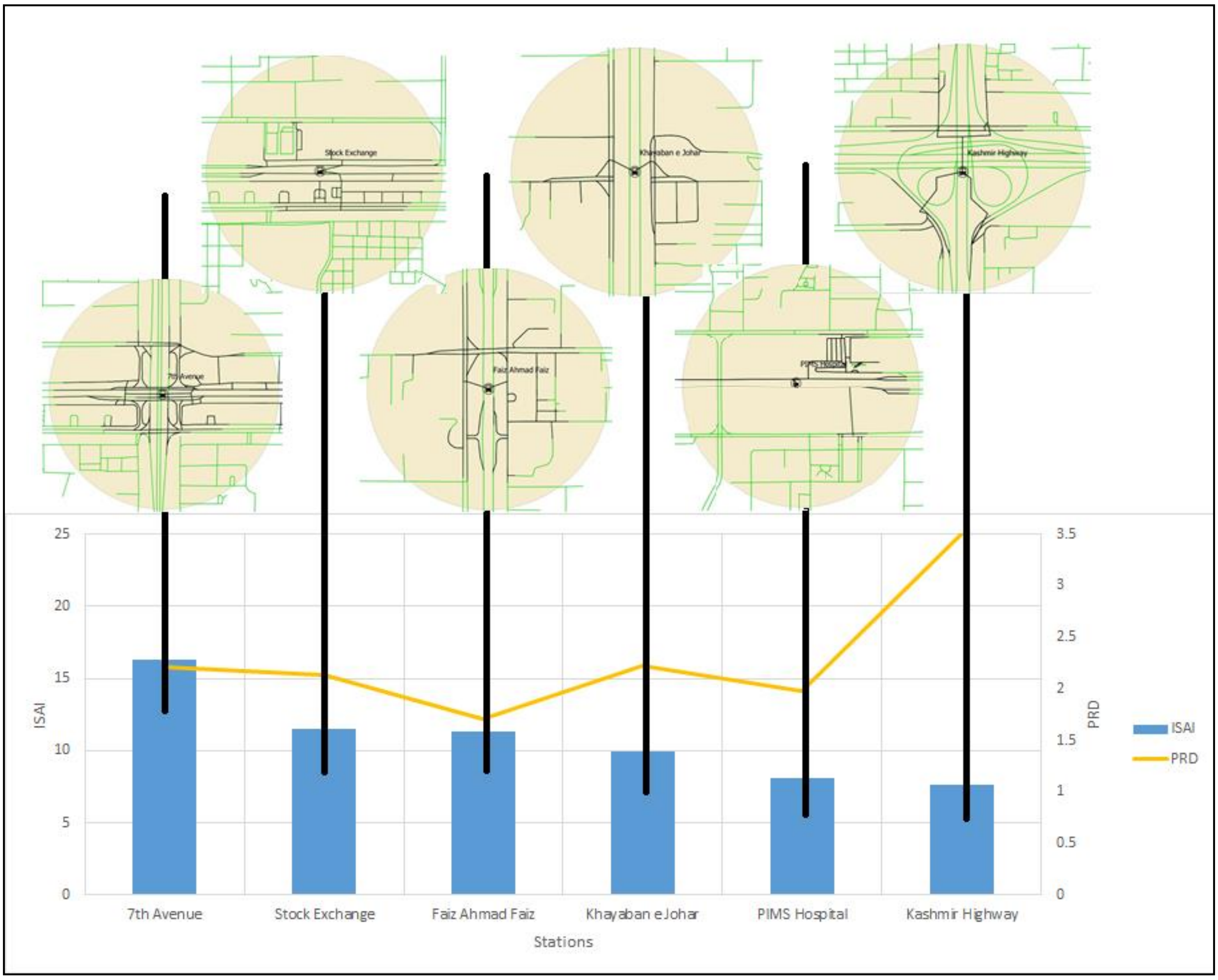

Figure 4-3 Index values for stations failing PRD test in Islamabad

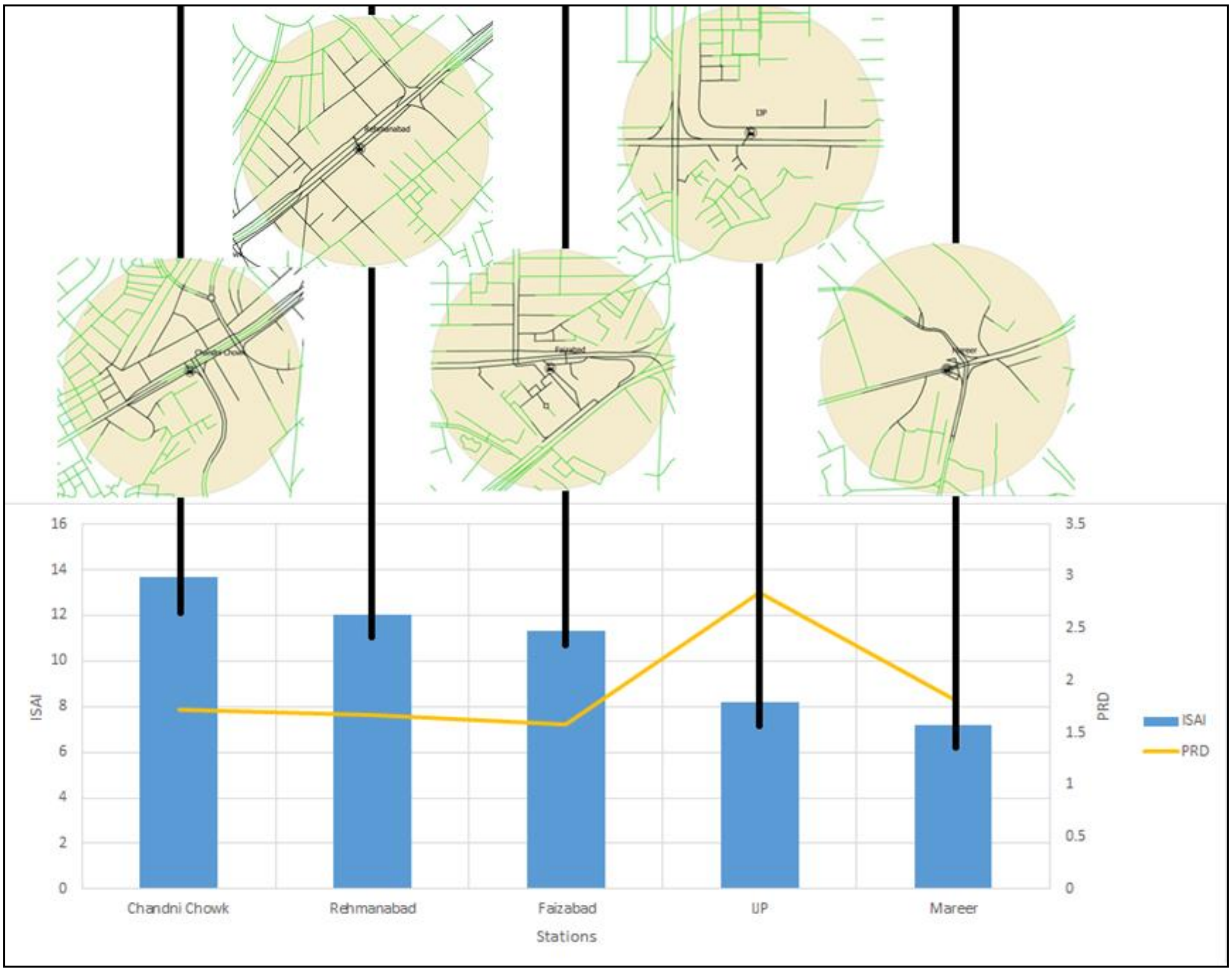

Figure 4-4 Index values for stations failing PRD test in Rawalpindi

The stations either have discontinuity in the surrounding network, presence of interchange, low-density lands or large premises in their vicinity. The impeding the tendency to walk.

shows the discrepancies in the network around the stations failing the PRD tests (PRD greater than 1.5).

The "7th Avenue", " Kashmir Highway" and "Faizabad" has Interchanges. "Kashmir Highway" has bigger interchange and eventually a higher PRD value and lower ISAI value as compared to the "7th Avenue" and "Faizabad" station. This grade separation in the interchange discontinues the network and thus the PRD value goes higher.

The other stations have discrepancies like discontinuity in the pedestrian path and the presence of large or deserted bodies. The "Chandni chowk" has a dense network more like grid-iron type but the immediate vicinity of station has no direct pedestrian paths emerging radially from the stations. Same problem exist in the case of "Rehmanabad", "Stock Exchange" and "PIMS Hospital" stations.

Large institutions/bodies/land means the presence of big institutions, depos, and electricity grid stations near the transit stations that create discontinuity in the surrounding network impeding the tendency to walk. These can be seen in the Table 4-2.

All these factors create discontinuity in the road network and decrease the network efficiency (increased PRD) hence impeding the tendency to walk.

Table 4-2 Problems in the street network around the stations failing PRD, Islamabad & Rawalpindi

Station No.	Station Name	PRD	Reason of Failure
4	7th Avenue	2.21	Presence of Interchange
10	Kashmir Highway	3.5	
15	Faizabad	1.58	
5	Stock Exchange	2.14	No direct radial pedestrian paths
6	PIMS Hospital	1.98	
19	Chandni Chowk	1.72	
18	Rehmanabad	1.67	
11	Faiz Ahmad Faiz	1.71	Large institutions/bodies/land near the stations
12	Khayaban e Johar	2.23	
14	IJP	2.85	
23	Mareer	1.83	

Figure 4-5 shows the summary of the whole analysis. Its shows the five main different types of street network configurations, that were observed in the twin cities, in sequence of decreasing walking accessibility to transit stations. The primary vertical axis (corresponding bar chart) shows the average values of ISAI and the secondary vertical axis (corresponding line chart) shows the frequency of PRD test passing for each type of street network. It has been observed from the figure that the street networks having spider-net shape has highest ISAI values and highest likelihood of passing the PRD test, followed by Grid-iron street network and Shared space environments. The street networks that have major interchanges and disconnectivities have lowest values of ISAI. Moreover, all the street networks, classified into these last two categories, have failed the PRD test.

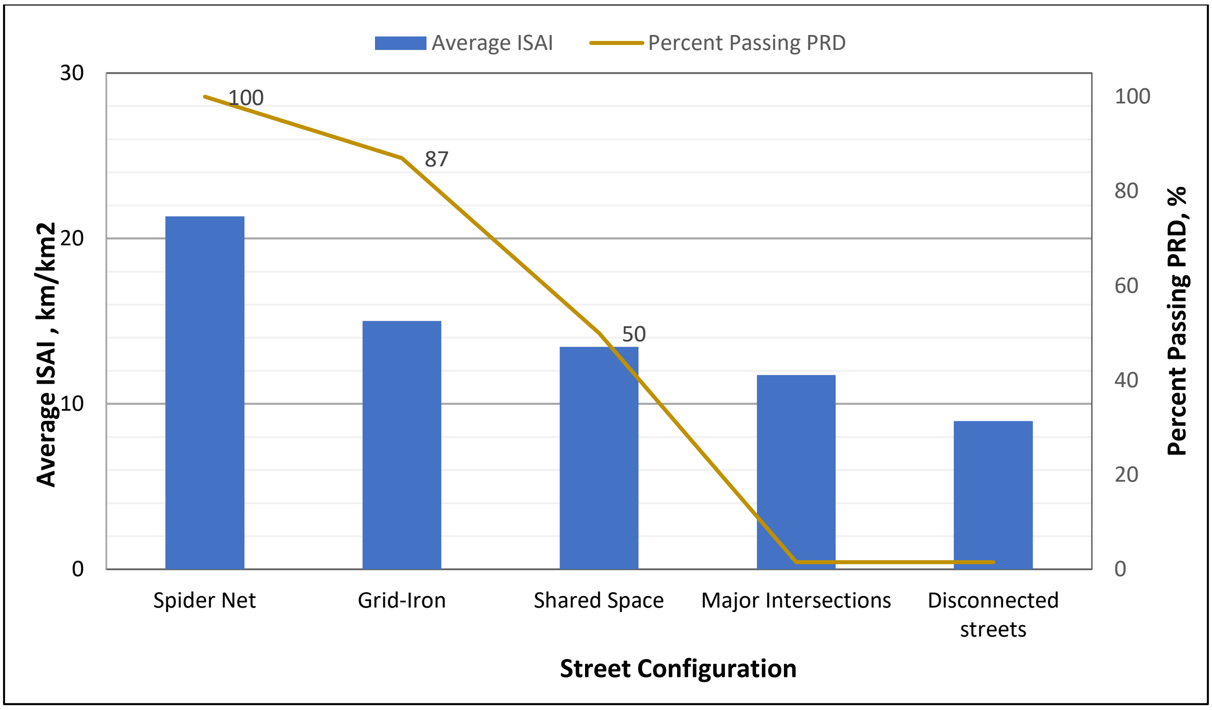

Figure 4-5 Summary of the Results that shows different street network types with their respective walking accessibility

CHAPTER 5: CONCLUSION

This study aimed at estimating the walking accessibility of the transit stations. It also compares the performance of stations located in different street network types concerning the parameters/variables in practice in the literature. The study area selected in this study is Islamabad-Rawalpindi Bus Rapid Transit. This project spans the cities of Islamabad and Rawalpindi, Pakistan, allowing the analysis on walk in various environments. Some major findings of this study are discussed below.

- The station located in the radial spider-net-shaped network has a higher value of ISAI and, hence, is more accessible than the grid-iron network. Rawalpindi gives better performance than the grid-iron network in Islamabad in general.
- The road network in Islamabad gives a higher value of ISAI when the street network has more loops and is interconnected.
- The station location that has high-rise buildings in the vicinity can get more pedestrians with lesser ISAI value. However, further study is required to ascertain it.
- A complete spider-net-shaped network has resulted in the highest ISAI value so far in this study.
- Stations located near shared space environment also has the potential for promoting walking for transit.
- There should be direct radial paths emerging from the station into the surrounding areas to increase its walking coverage and efficiency.
- Stations that are located near large bodies like power grid stations, depots, major interchanges, and deserted lands discourage walking thereby lowering the walking efficiency of a network.

Based on its findings, the research article proposes an ideal case scenario of the transit station location. It proposes that the station should be located in densely populated commercial areas having high population density. Large bodies and traffic interchanges should come at the peripheries of the accessibility buffer. Shared space concept should be encouraged near stations. There should be direct radial paths near station connecting it to the inner areas of ped-shed. In residential areas, paratransit and shuttle services should be provided to increase the coverage of the stations.

5.1 RECOMMENDATIONS

This research has discussed the estimation of walking accessibility of stations in different environments through parameters/variables used in the literature. This signifies the effect of station location on its walkability. Moreover, the method can be improved by considering the effect of multi-storey buildings in the analysis. As the current study is based on road network length alone, it ignores the effect of upper floors of high-rise buildings that comes inside the actual accessibility buffer or ped-shed. By considering the total floor area inside the ped-shed, a more precise station's walking coverage can be obtained. The future prospect in this area should also target the correlation between accessibility indices with the real passenger counts on the stations. This will conclude the effect of station location on the transit ridership. Adding to that, the proportioning of number of stations in commercial and residential areas can also optimize the ridership for which a detail research is required.

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APPENDICES

Appendix A: The limitations in the past literature that are addressed here while assessing the walking accessibility to transit stations

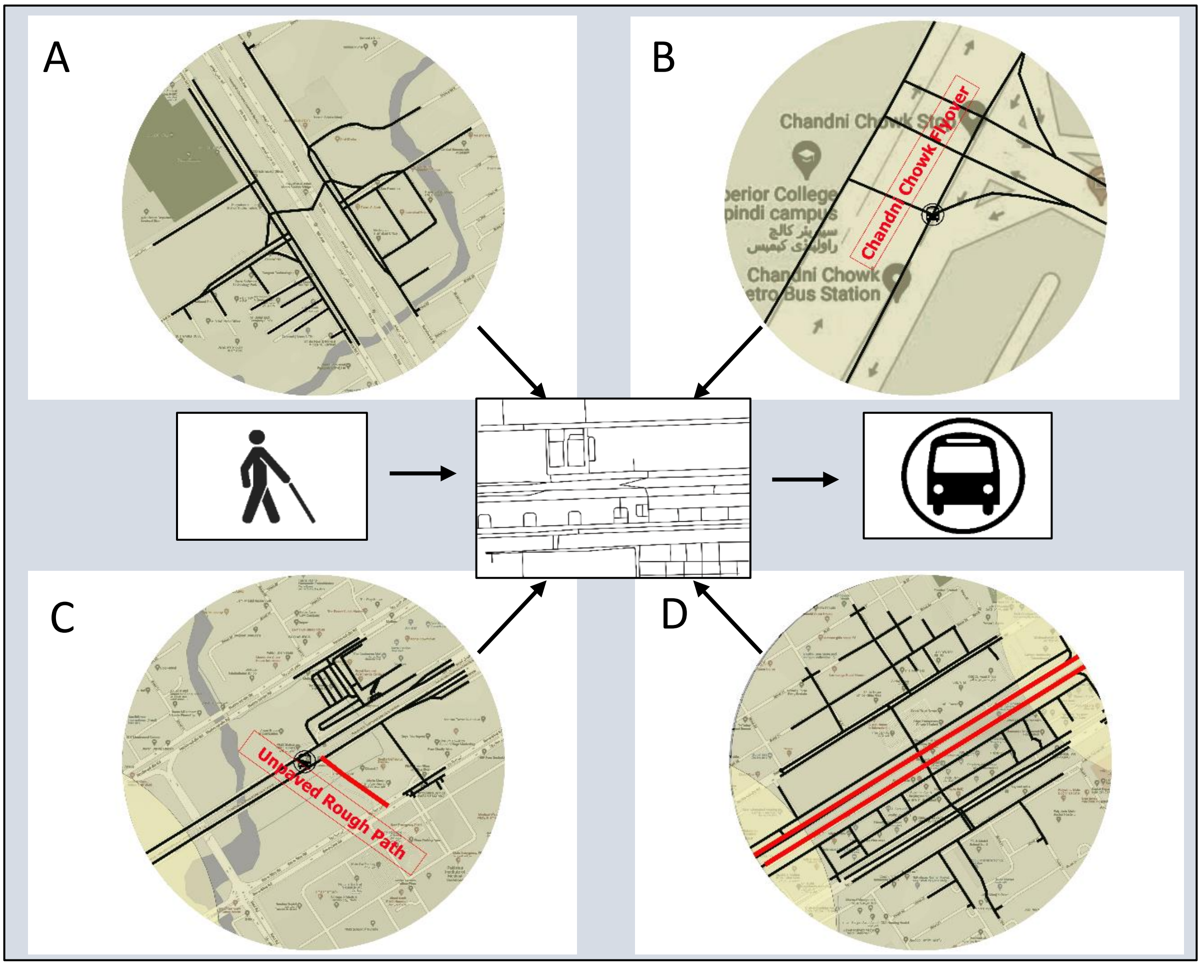
Previous Research	**This Research**
Untargeted Walking Accessibility	Walking Accessibility for Transit
Proximity based	Actual Walking Distance Used
Street Configuration Ignored	Street Configuration considered
Google Maps and OSM used directly	OSM maps modified and then used
Street undefined	Street properly defined

Appendix B: The data acquisition has been done using Google Earth, OSM libraries and Google Maps

Some missing streets added from field visits within the 400 meters radius around the transit stations

Appendix C: The figure shows the examples of non-walkable streets and walkable streets

Non-walkable streets are those which has no pedestrian facilities (such as footpaths) or no pedestrian activities, like major ariterials, flyovers, and unpaved rough paths shown in street networks A, B and C respectively. The walkable streets are those which has noticebale pedestrian activities or pedestrian facilities as shown in street network D.



Appendix D: Table shows the station name, highway class on which station is located, number of lanes of highway and station's elevation with respect to highway

S.No	Station Name	Highway classification	Number of lanes incl. service roads	Elevation of station
1	Pak Secretariate	Collector	8	At grade
2	Parade Ground	Minor Arterial	10	At grade

3	Shaheed e Millat	Minor Arterial	10	At grade
4	7th Avenue	Minor Arterial	10	At grade
5	Stock Exchange	Minor Arterial	10	At grade
6	PIMS Hospital	Minor Arterial	6	At grade
7	Katchari Chowk	Minor Arterial	6	At grade
8	Ibn e Sina	Major Arterial	10	At grade
9	Chaman	Major Arterial	10	At grade
10	Kashmir Highway	Major Arterial	14	Underground
11	Faiz Ahmad Faiz	Major Arterial	10	At grade
12	Khayaban e Johar	Major Arterial	10	At grade
13	Potohar	Major Arterial	10	At grade
14	IJP	Minor Arterial	9	At grade
15	Faizabad	Minor Arterial	9	Elevated
16	Shamsabad	Minor Arterial	10	Elevated
17	6th Road	Minor Arterial	10	Elevated
18	Rehmanabad	Minor Arterial	10	Elevated
19	Chandni Chowk	Minor Arterial	10	Elevated
20	Waris Khan	Collector	5	Elevated
21	Committee Chowk	Collector	8	Elevated
22	Liaquat Bagh	Collector	7	Elevated
23	Mareer	Collector	5	Elevated
24	Saddar	Collector	6	Elevated

Appendix E: The table shows the classification of stations into five major street network types observed in the study

Street Network Type	Stations	ISAI	PRD
Spider Net	Waris Khan	26.8710191	1.31
	Committee Chowk	22.6910828	1.31
Shared Space	6th Road	14.6297771	1.37
	Shamsabad	13.4753185	1.24
	Chandni Chowk	13.6544586	1.72
	Rehmanabad	12.0421975	1.67
Grid-Iron	Shaheed e Millat	20.0437898	1.28
	Chaman	18.968949	1.29
	Potohar	17.3765924	1.48
	Parade Ground	14.7890127	1.42
	Ibn e Sina	14.1719745	1.36
	Katchari Chowk	11.285828	1.26
	Stock Exchange	11.5246815	2.14
	Saddar	11.9426752	1.36
Major Intersections	7th Avenue	16.3017516	2.21
	Kashmir Highway	7.62340764	3.50
	Faizabad	11.3057325	1.58
Disconnected streets	Faiz Ahmad Faiz	11.3455414	1.71
	Khayaban e Johar	9.93232484	2.23
	IJP	8.20063694	2.85
	PIMS Hospital	8.12101911	1.98
	Mareer	7.1656051	1.83