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Assessing the Serviceability Status of Existing Transport Network by Using Geospatial Techniques in Metropolitan City Lahore

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Abstract. Reliable and an efficient Public Transport plays key role in establishing sustainable Urban Transport system and healthy environment in any city. Public Transport equity in terms of easy access for the commuters is very crucial. With the drastic increase in population and cities extent in developing countries like Pakistan, the travel demand is recklessly increasing which urge to provide efficient public transit which may cater the ever increasing transport demand. Lahore being the provincial capital of Punjab and the second most densely populated city of Pakistan, has a remarkably large transportation network. The case study presented an advanced approach to determine the population with walking access to transit stop of Lahore Public Transport network, by using Geographical Information System (GIS). This approach is quite efficient, reliable and helpful to investigate the effectiveness of transit network, user's access to transit stops and spatial gaps in the transit facilities. GIS-based network service area analysis has been utilized to find the transit stop service area of the existing public transport network in metropolitan city Lahore. To find the transit stop service area, suitable walking time of 8 min or threshold distance of 624 m with walking speed of 78 m/min has been used as a standard. Transit stop service area has been used to find the population with walking access to a transit stop. The results reveal that only 40% of the total population was in suitable walking distance, which shows that less serviceability is due to the improper spatial distribution of existing transit stops across the transit route. The results also identify the population which is not in suitable walking distance to transit service. This study concludes that Geospatial Techniques are significant in assessment of the effectiveness and subsequently measuring the gaps in the existing transport network. Thus, on the basis of these results sustainable solution would be presented to enhance the efficacy of the integrated public transport.

Keywords: accessibility, service area analysis, GIS, transit stops, spatial distribution

Introduction

Public Transport (PT) has been considered as a significant means of social and sustainable transportation system, which may improve the quality of urban life Mamun (2011). Transport accessibility caters the urban growth and key factor for enhancing the sustainability in urban areas Ford *et al*. (2015). To enhance the social and economic performance of urban areas, it is necessary to provide good and effective connectivity between resources and destinations. There is a dire need to establish common parameters for transportation analysis among many metropolitan cities with different dimensions and frame works to meet the ever increasing demand for global collaboration towards more sustainable urban structures and environments Bok and Kwon (2016).

In transportation system and analysis accessibility is the most important concept Lei and Church (2010). Accessibility may be defined as spatial relation of one location to other specified location Park (2012). Walking access is proximity of the Passenger's origin or destination to the nearest transit stop Foda and Osman (2010). Transit stop accessibility plays a role as catalyst in economic development Van (2011), environmental objectives Grengs (2010) and equitable access for all socio-economic groups Foth *et al*. (2013). Saghapour *et al*. (2016) measured the Public Transport accessibility in Melbourne area, Australia by using Public Transport Accessibility Index. He investigated that, there is a higher probability of Public Transport patronage in areas with higher levels of accessibility. EI-Geneidy *et al*. (2010) determined transit system effectiveness can be achieved by measuring the percentage of population served in the metropolitan region. He also identifies the causes of redundancies and gaps in transport system. Time and service frequency are important factors to users in context of Public Transit Curtis *et al*. (2010). Service frequency plays a vital role

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driving public transit patronage Wang (2011). It is universally accepted that 400 m walking distance with mean walking speed between 80-95 m/min is the maximum distance a transit user willing to travel to reach their nearest transit stop Biba *et al*. (2010), while other distances have also been used in urban areas i.e. 300 m, 500 m and 800 m, Mavao *et al*. (2012).

Urbanization creating a big impact on transportation system in mega cities of Pakistan, Qureshi and Lu (2007). Urbanization is the key factor in increasing vehicle manufacturing, expansion of road transportation, roads expansion, and it effects the social networking Chai *et al*. (2016). The abandoned increase in urbanization, motorization and lack of transport planning creates many social, economic and environmental imbalances in city like air pollution, poor transport infrastructure and traffic congestion, which result equity issue Wong (2012). The population in Asian countries is continuously increasing due to which Urban Transport facing worsening conditions. So, urban planners and transport planners should take safety measure to avoid critical transportation problems in future.

This research emphasis on determining the population with walking access to transit stop in conjunction with geometrically corrected pedestrian network, spatially adjusted transit routes and landuse data sets by using GIS based service area analysis. Distances covered by the transit user in accessing the transit stops were used to determine the threshold distances of the transit service area and estimate the population covered by public transport. Suitable walk time of 8 minute or threshold distance of 624 m with walk speed of 78 m/min has been used as a standard to find the transit stop service area.

The study objectives are outline below:

- To develop the robust databases encompassing geometrically corrected network dataset Urban Transport routes, population and land use in study area.
- To investigate the population with walking access to existing transit services in study area using advanced Geospatial approach.
- Identification of the poorly served areas along with potential causes.

Materials and Methods

Figure 1 shows the material and methods utilized in this study to determine the served population in study area.

Study area. Metropolitan city Lahore has been selected for this study. It is the second most densely populated city in Pakistan and has a remarkably large and complex transportation network. It is situated at Latitude 31°15' 31°45' N and Longitude 74°01' 74°39' E.

The study area comprises of 274 Union Councils (UCs) which cover all existing Public Transport routes and urban population. The outer UCs have comparatively larger area from which 70% area comprises of an open and undeveloped land, while inner UCs have larger developed areas and maximum number of transit facility. The population of the Lahore city has been estimated about 10 million, with a growth rate of 3.32% per annum, induces growing city and increasing car ownership. The demand for Public Transport has been increased because large numbers of commuters use Public Transport for migration in different parts of the city. An integrated public transport system was proposed in Lahore to develop sustainable Public Transport system and deal with transportation related issues. Integrated Public Transport network includes HOV (High Occupancy Vehicle) large buses and mass transit, LOV (Low Occupancy Vehicle) mini buses, and Feeder routes that are integrated with high quality BRT systems like Metro and provide access to terminal. According to Lahore Transport Company (LTC), currently, Public

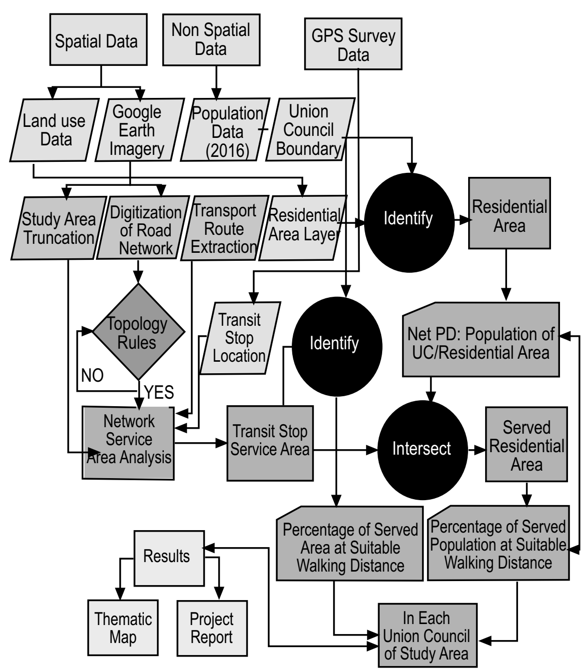

Fig. 1. Working architecture of study area.

Transport services are providing on 13 operational HOV routes, 22 LOV routes and Metro with integrated 14 operational feeder route.

The prevailing transport situation in Lahore clearly shows that there is a need to develop sustainable and efficient urban Public Transport system to overcome any future transportation related problems. GIS is a power tool that can be applied in travel demand modeling, transportation hazard analysis, finding best route, calculating service area with associated population and for many other transportation analyses. (Biba *et al*. (2010). Figure 2 depicts the study area map.

Data of the study. The present research has collected a large set of data that later incorporate into GIS to perform Network Analysis. A comprehensive road network data, land use and existing Public Transport data were used in GIS to find out population with walking access of 8 min.

Road network. Detailed road network was digitized on high resolution satellite imagery. Pedestrian/Road network is the essential parameter to measure the accessibility to transit stop. Commuters can access their desire location/transit stop through pedestrian road network surrounding each stop. To develop geometrically corrected network dataset, the edge–node topology was applied on road network data. Geometric errors were removed by applying topological rules prior to use this data in network analyst Javed *et al*. (2013).

Walking component was developed by using road network data by measuring walk time and length of each road segment. The following simple equation was used in ArcGIS 10.3 to develop walking component.

$$S = v \times t$$

where:

t = Walk time (min)
S = Length of road segment (meter)
v = Travel speed (meter per min)

Spatial adjustment of transit data and landuse development. Existing Public Transport route data was acquired form Lahore Transport Company (LTC). Transit data was overlaid on Google Earth satellite image to check the spatial accuracy of data and it was observed that the provided routes were shifted from actual path. The transport network data must be spatially adjusted with road network data to find transit catchment area in Network Analyst. For this purpose, Spatial Analyst tool of ArcGIS has been utilized. Road network curves on the Georeferenced satellite imagery have been used as reference points for spatial adjustment.

Figure 4 illustrate existing Public Transport routes overlay on land-use available in the study area. Gulhan and Ceylan (2016) cited in his research, he determined the transportation investments still stalwartly affect land use patterns, urban masses and housing prices. Interaction

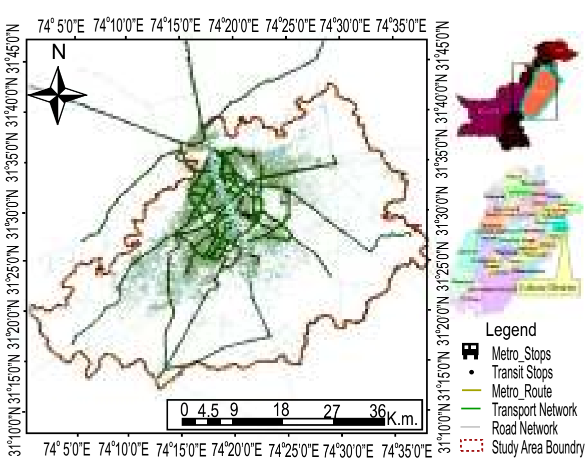

Fig. 2. Study area map.

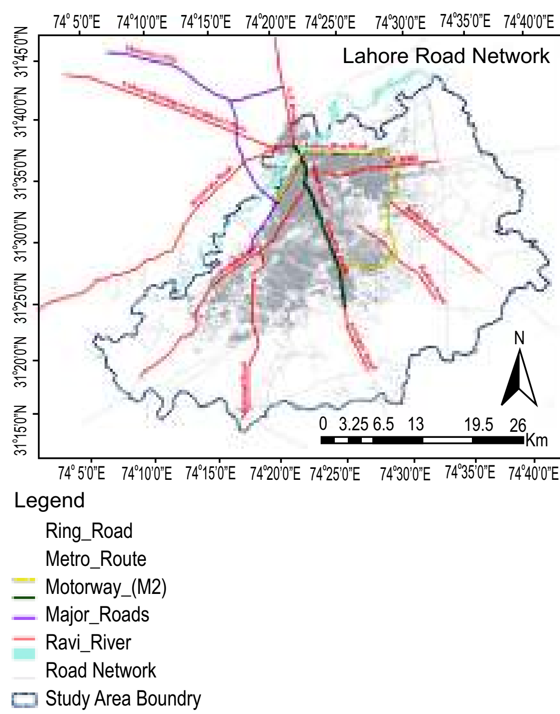

Fig. 3. Road network in study area.

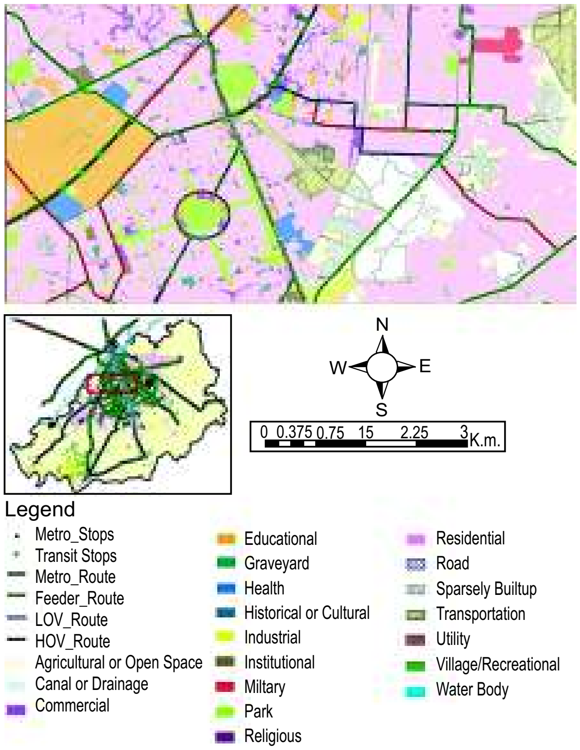

Fig. 4. Existing public transport routes and landuse.

between land use and transportation is the elementary factor for a trip generation.

Network analysis. ***Identification of areas serviced by public transit.*** All transit stops have been imported as point features along the pedestrian network. Network dataset must be developed on error free data which have F node, T node, F & T minutes and one-way restriction attributes in Network Analyst. To create Network dataset, it is necessary that all feature classes in the dataset must be connected with each other at every node, it represents the real time network linkage within study area. Area served by Public Transport was created through the Network Analyst Tools of ArcGIS 10.3 using suitable walking time of 8 min or threshold distance of 624 m with walking speed of 78 m/min. It is universally accepted that, suitable walk time of 8 min is the maximum distance a transit user willing to travel to access their nearest transit stop Finnis and Walton (2008). This service area includes all the streets that can be access within eight minutes from that facility. Once the service areas created, it can be utilized to identify the served population and will help to evaluate accessibility.

Calculation of served population. The results of transit stop service area were further utilized to calculate the population with walking access. Served population has been calculated by overlaying different layers in GIS data framework. Served population is describe by the following formula:

$$\text{Net population density} = \frac{\text{Total population}}{\text{Total buildup area}}$$

Served population = Net PD × served residential area

The effectiveness of transportation system depends on efficient land use decisions and well-arranged residential area densities Handy (2005).

Results and Discussion

Results evidenced the full capability of GIS based service area analysis to precisely determines the population within a service area of a transit route in Lahore district.

Figure 5 shows the service area of existing public transport routes by taking standardized walk time of 8 min. Result reveal that, irregular service area polygons are due to the unavailability of pedestrian network in study area. The figure depicts that, service area polygon of some transit stops is getting overlapped with service area polygon of other transit stops, which shows the improper spatial distribution of transit stops. Ammons (2001) investigates the reasons for overlapping of transit service area and find that transit stop spacing typically ranges from 656 to 1,968 feet in urban area which is such a small distance between two stops. This small distance creates overlapping zone between stop service areas on the same route as well as stops of adjacent route. Transit stops should be spaced to minimize walking distances in areas which have high public transport demand and to reduce the number of bus stoppages. Transit user density can be increased by providing spatially well distributed transit stops (Foda and Osman, 2010).

Figure 5 shows that transit stops are more closely concentrated in the central and southwest union councils (UCs) providing comparatively good serviceability status in district. On the other hand, transit stops are sparsely distributed in west and northeast Union Councils (UCs) resulting in low or poor serviceability in district.

The results reveal that, population is partially served by existing public transport in the study area. Figure 6 depicts that, central and southwest union councils (UCs) have comparatively good serviceability due to adequate and spatially well distribution of transits stops. On the other hand, west and northeast union councils (UCs) have low or poor serviceability due to less/null transport facilities. Most of the union councils (UCs) does not have any transit stops despite of having sufficient residential area and public transport demand.

Table 1 depicts the UC wise serviceability status in study area. Only 40% of total population within observed threshold walking distance in study area. Although UC no 235 (Township-Sec-B) and UC no 232 (Township-I) have high serviceability due to well distribution of transit stops and efficient pedestrian network, while UC no 217(Shah Kamal Clifton Colony) and UC no 154 (Kotli Peer Abdul Rehman) are completely unserved which means people living in this particular zone have no transit facility and may be using para transit modes or Private Transport to access nearest transit stop.

In Fig. 7, it has been observed that, serviceability of only 40% population reflecting serious lapses and gaps in existing transport infrastructure within. study area Major causes behind this poor serviceability are improper spatial distribution pattern of transit stops, absence of commuter mapping and insufficient pedestrian network. Moreover, existing transport routes are overlapping in many parts of study area while on other side there are some potential demand areas without having any sort of coverage. Consequently, there is a dire need to revise the route's alignment and stops distribution on the basis of relevant parameters in order to enhance the potential coverage. This research is helpful to propose new optimal location for transit stop and to modify the spatial location of already existed transit stop in order to enhance the efficacy of public transport.

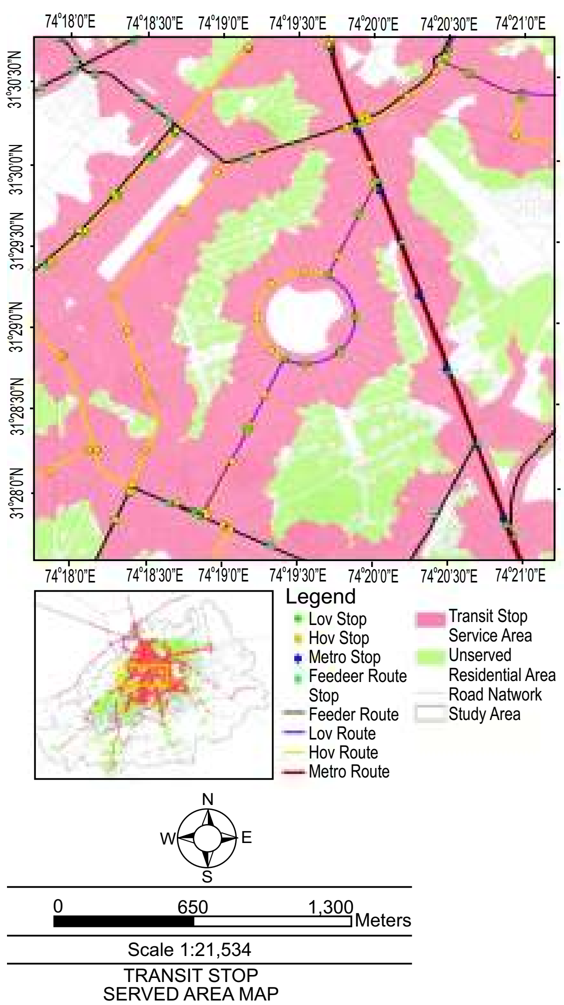

Fig. 5. Transit stops serviceability.

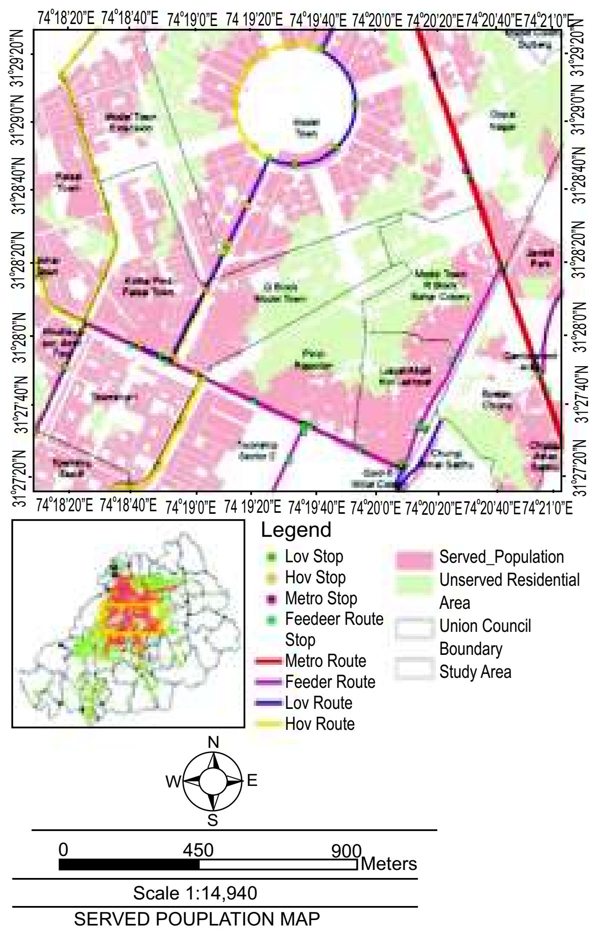

Fig. 6. Served population.

Table 1. UC wise serviceability status in study area

UC code	Served population (%)	UC code	Served population (%)	UC code	Served population (%)	UC code	Served population (%)	Served code	UC population (%)
009	65%	063	87%	107	57%	163	16%	220	34%
012	9%	064	98%	108	0%	164	12%	221	50%
013	11%	065	48%	109	1%	165	28%	222	44%
015	68%	066	98%	110	15%	166	0%	223	42%
016	81%	067	1%	111	38%	168	43%	224	78%
017	95%	068	67%	112	34%	169	72%	225	40%
018	24%	069	55%	113	58%	170	90%	226	49%
019	71%	070	70%	114	34%	171	92%	227	88%
020	54%	071	9%	115	29%	172	99%	228	50%
021	3%	072	67%	116	5%	173	97%	229	53%
022	99%	073	50%	117	8%	175	37%	230	95%
023	46%	074	59%	118	53%	178	4%	232	100%
024	27%	075	65%	119	9%	182	8%	233	93%
025	16%	076	99%	120	7%	183	17%	235	100%
027	98%	077	93%	121	35%	184	83%	236	89%
028	46%	078	86%	122	48%	185	65%	237	95%
029	37%	079	93%	123	49%	186	89%	238	96%
030	65%	080	49%	124	92%	187	80%	239	14%
031	37%	081	63%	125	24%	188	97%	240	25%
032	69%	082	66%	126	4%	193	13%	241	44%
033	98%	083	98%	128	44%	194	9%	242	28%
034	99%	084	63%	129	33%	195	90%	243	10%
035	97%	085	48%	130	1%	198	53%	244	24%
036	94%	086	46%	141	0%	199	70%	245	37%
037	99%	087	0%	142	62%	200	39%	246	17%
038	87%	088	33%	143	24%	201	83%	247	20%
039	99%	089	98%	145	56%	202	57%	248	15%
044	1%	090	45%	146	96%	203	39%	250	27%
045	22%	091	85%	147	74%	204	0%	251	69%
048	95%	092	67%	148	18%	205	36%	255	23%
049	50%	093	9%	149	57%	206	66%	256	20%
050	36%	094	91%	150	59%	207	69%	257	5%
051	48%	095	81%	151	14%	208	77%	258	0%
052	91%	096	24%	152	56%	209	90%	259	3%
053	60%	097	48%	153	47%	210	89%	262	8%
054	73%	098	46%	154	0%	211	81%	266	13%
055	25%	099	19%	155	30%	212	72%	267	4%
056	65%	100	78%	156	69%	213	49%	268	24%
057	86%	101	89%	157	69%	214	83%	269	7%
058	27%	102	63%	158	70%	215	73%	270	0%
059	19%	103	19%	159	0%	216	2%	271	65%
060	63%	104	84%	160	3%	217	0%	272	9%
061	88%	105	10%	161	7%	218	29%	273	11%
062	84%	106	0%	162	37%	219	47%	274	68%
Total			40%						

In scenario 1, as the maximum walk time threshold of 8 minutes is considered across developed countries, but in this study serviceability with this walk time only provides 40% population coverage. These results are quite alarming being the metropolitan city and provincial capital. In scenario 2, threshold has been slightly increased upto 10 min either to check that any sufficient increase in serviceability would occur, but the obtained results do not provide any reasonable increment. Consequently, these results translate very serious issues regarding the Public Transport infrastructure which demand immediate attention and remediation.

Conclusion and Recommendations

This study illustrates the capability of GIS based network service area analysis to examine the deficiencies in

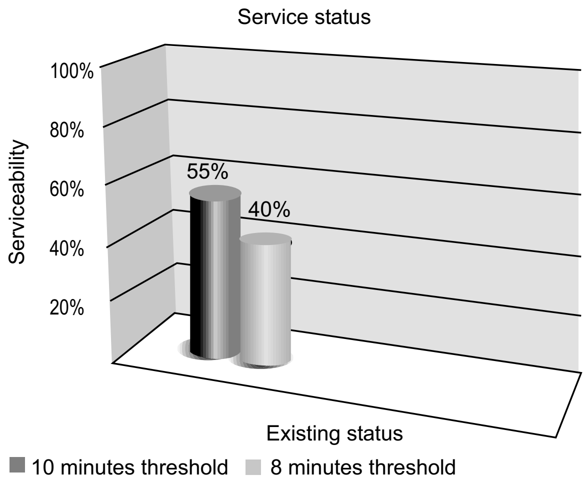

Fig. 7. Serviceability comparison in different time thresholds.

existing Public Transport network and also identifies the areas where improvement needed. There is a dire need to propose new routes along with transit stops proper distribution to improve/maximize the service ability status especially in those areas with poor/less service ability. Subsequently, a transport network having good accessibility for commuters will ultimately leads in establishing a reliable transport system and reducing the private vehicles and traffic congestion. In addition, provision of sustainable transport system will establish equity in ecology and environment across the study area.

This is the right time to make serious efforts to design a spatial decision system for sustainable integrated Urban Transport in city by keeping in view the general public issues. This may be done by conducting a comprehensive study which must incorporates the data of road geometry public demand, commuter's density, unserved pockets and growth pattern of the city. Sustainable Public Transport models of other developed cities i.e. London, Turkey, Tokyo etc. may also be followed and replicated in study area. The local government departments and other stake have to onboard to mitigate this serious challenge otherwise existing inefficient and unreliable Public Transport system will lead to big chaos in terms of huge increase in personal vehicle in city. Concerned transport agencies must organize such periodic studies at least in the major cities of Pakistan to assess the Public Transport service delivery to the people.

Conflict of Interest. The authors declare no conflict of interest.

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