Original Paper

Effect of Walkability on Users Choice of "Walking" the Last Mile to Transit Stations: A Case of Delhi Metro

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Abstract

There is growing recognition of the importance of Last Mile Connectivity (LMC) to mass transit systems. In the context of Delhi, albeit a shift can be seen in the provisioning of LMC, and despite previous studies indicating that more than 50% of metro rail users walk to and/or from metro stations, yet the seriousness with which pedestrian environment is woven into transit planning is lacking.

The paper is based on an empirical study conducted by the author, of approximately 800 samples of metro users surveyed across seven stations of Delhi Metro, representing different station typologies, ridership and locational contexts. The paper focuses on the "walk" choice of users across a variety of factors related to their socio-economic strata, trip characteristics and station context. A parallel study is conducted to audit the pedestrian environment within one kilometre distance around each station. The paper further attempts to investigate whether pedestrian environment affects user choice of opting for "walk" as the last mile choice. It also ranks the performance of the case stations in terms of various attributes of walkability.

In conclusion, the paper contends that overall walkability environment offered to transit commuters is crucial in the share of walk trips for last mile commute and the distance commuters are willing to walk. It recommends that walking as LMC choice needs to be promoted through enhanced user experience in absence of which a significant amount of last mile travel will happen through unsustainable mechanised modes.

Keywords

last mile connectivity, sustainable mobility, transit access, pedestrian environment, walkability

1. Introduction

In the quest to cope up with some of the negative externalities of urbanisations in the form of traffic congestion and rising levels of air pollution, cities all across the world are today grappling to reduce the number of personal automobile trips. A variety of factors affect travel choices between public vis-à-vis private transport; and cities are adopting various strategies to divert choices towards the latter. One of the several responses is promoting public transport and other forms of green transport but this is easier said than done. Since private modes offer a variety of advantages such as demand mobility, comfort, status, speed, and convenience (Rodrigue, 2013) hence despite the fact that increasing number of cities, especially in the emerging economies having introduced mass transit systems, ridership remains lower than what would be desired. Even amongst transit users, sadly a considerable proportion use unsustainable modes to access the transit stations itself. This is manifested through large chunks of land at metro stations devoted to parking areas meant for private motorised vehicles.

As research (Stopher et al., 1974) suggests that the attractiveness of public transport can be decomposed into four generic elements: safety, cost, time, comfort and convenience, most transit planning focus on improvement in these elements, however, of the transit system per se and not of the overall journey which includes the first (FM) and the last mile (LM) connectivity, hereafter referred to as LMC. LMC refers to both the initial and final leg of delivering connectivity from origin to transit system (access/ First Mile) and from transit system to destination (egress/ Last Mile). The origin may be home-end or non-home end of a trip and similarly the destination may be home-end or a non-home end of the trip.

Numerous literature indicate that connecting ends of transit systems, in other words, the LMC, are the weakest link (Cervero, 1998; Givoni, Moshe and Rietveld, 2007; Cheong, Chik, and Toh, 2010) and that they can significantly influence the overall appeal of public transport given their substantial contribution in terms of travel time and travel discomfort (Krygsman, et al., 2004; Rietveld, 2000; Tay, 2012). The resultant impact is manifested in terms of less than desirable ridership and/or unsustainable modes used for LMC. Recent studies (Hengky, 2012) endorse this through citing at least two LMC issues, that can arise out of lack of adequate walking and cycling infrastructure and unfavourable walking and cycling conditions and built environment (Loutzenheiser, 1997; Quade et al., 1996). A report (Nelson/Nygaard, 2009) on assessing last mile also claims that commuters 'walk' at least one end of the trip: one result (Hutchinson, n.d. in Clever, 2011) indicating that most office workers are only willing to take public transport if they can walk to their final destination. Both pedestrian environment (and walkability) and walking as an access/egress mode to transits have been researched upon extensively, but little work is available on how pedestrian environment influences users' decision to walk the FM/LM.

This paper is drawn from an ongoing doctoral research by the author on LMC for Delhi metro rail. While the study takes a comprehensive planning approach for LMC provisioning, the scope of this paper is to investigate whether and how pedestrian environment influence the user's choice of "walk"

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as last mile mode option.

2. Methodology

2.1 Database / Survey Design

The paper is based on primary surveys conducted at seven metro stations (described later in Table1) of Delhi Metro Rail. The metro stations selected are on two lines—blue and yellow—that have the highest ridership in the network. Criteria considered for station selection include ridership, station typology, last mile transport supply, adjacent built environment characteristics.

Transit commuter surveys included direct questionnaire interview of first / last mile users of these seven case stations covering 850 samples in all. Non-probability quota sampling technique was used and surveys conducted at entry / exit points of station during four hours in the morning and four hours in the evening. Surveys were conducted on weekdays as the focus of the study is primarily on regular type of trips. Information was collected on first / last mile and main haul trip characteristics, user's socio-economic profile, user's attitude, stated preference in ranking and rating of first/last mile choices. The second part of the surveys concerns with an assessment of the pedestrian infrastructure and environment around these case stations. A self-audit for 1 km of all major streets adjoining and leading to / from the stations is carried out. In addition built environment mapping is done for 1 km radius around stations, covering land use and building heights (not reported in this paper).

2.2 Analytical Approach

Part one of the analysis covers the Last Mile Trip characteristics with emphasis on "walk" trip behavior of overall and individually first / last mile trips. The significance of "walk" as a trip choice is tested against user's socio-economic strata and also against other trip characteristics using software SPSS. These are done at an aggregate level for all stations. Some important descriptive statistics such as modal shares and average trip length (ATL) for walk trips have been discussed at disaggregated station levels.

In the subsequent section a Pedestrian Environment Index (PEI) is developed using audit findings. The PEI is broadly divided into 2 categories namely "pedestrian infrastructure" and "route quality/experience". The indicators and attributes "I" at each station "s" is assigned a score, weights are assigned to each attribute. The weighted scores P_i are then derived from from the weights and scores for each attribute, and sum of all P_is are computed as converted percentage points for the audited station. Since there are only 7 case study stations, statistical correlation/significance testing is not attempted; however the individual P_i and overall PEI are assessed against walk trip characteristics of last mile users.

3. Case Study Profile

3.1 Delhi Metro Profile

Since its operation in 2002 the Delhi Metro network has expanded to presently (till 29th March, 2017)

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(DMRC, 2017) cover 213 kms of network length in 7 lines. The blue, yellow, and red lines carry the highest ridership. The average daily ridership of metro has risen from about 0.12 millions in 2004-05 to 2.76 millions in 2016-17.

3.2 Case Stations Profile

Stations selected for the present research study represent medium to low ridership categories with different typologies. The last mile transport supply available also vary amongst the stations. They also differ in terms of the landuse surrounding the stations and the nature of planned built environment (Refer Table1).

Table 1. Case Study Stations Operational Characteristics and Surrounding Context

Station Name	Operational Characteristics			Physical Context	
	Avg.Daily Ridership* (April'17)	Typology	Last Mile Transport Supply	Adjoining Landuse	Nature of Planning
Mayur Vihar-I (MV)	19,413	Mid-block	Cycle-rick, E-rick, Auto-rick, shared auto, Feeder bus	Residential	Planned
Dwarka Sec-10 (D10)	9,761	Midblock	Cycle-rick, E-rick, Auto-rick, shared auto,	Residential Institutional	Planned
Noida City Centre (NCC)	36,733	Terminal	Cycle-rick, E-rick, Auto-rick, shared auto, City bus, Chartered bus	Commercial (partially developed), Residential	Planned, Urban village
Dwarka Mor (DM)	42,928	Midblock (acting as terminal)	Cycle-rick, E-rick, Auto-rick, shared auto, Feeder bus, City bus, Chartered bus	Commercial Residential	Planned, Urban village
Chhatarpur (CP)	36,036	Midblock (Delhi outskirts)	Cycle-rick, Auto-rick, shared auto, Feeder bus	Residential Commercial (informal)	Planned, Urban village
Vishwavidyalay (VW)	25,593	Mid-block	Cycle-rick, E-rick, Auto-rick, shared auto, City bus, PBS	Residential Institutional	Planned
Green Park (GP)	27,900	Mid-block	Cycle-rick, Auto-rick, Feeder bus	Residential Institutional Commercial	Planned

Source: Primary Survey, 2017; * DMRC, 2017

4. Analysis

4.1 Mobility Characteristics

4.1.1 Trip Attributes

Table 2 shows the trip characteristics in terms of time, cost and distance of the entire trip and its sub-components including the first and last mile and the main haul (MH). The waiting time for each section of the journey have been included in their respective segments. The FM and LM together constitute about 40% & 48% of the time and cost respectively whereas comprise of merely 18% of the distance reflecting poor last mile services.

Table 2 .Trip Characteristics of Transit Journey Components

Last Mile Components		Time (in minutes)		Cost (in Rs.)		Distance (in kms)	
		Mean	%	Mean	%	Mean	%
1	FM	12	18	9	19	1.6	8.0
2	MH	40	61	25	52	16.5	82.5
3	LM	13	20	15	32	2.0	10.0
1+3	FM+LM	25	39	23	48	3.5	17.5
2+(1+3)	Total Trip = MH+(FM+LM)	65	100	48	100	20.1	100

Source: Primary Survey, 2017

4.1.2 NMT and Walk Modal Share of All FM & LM Trips

The predominant mode for covering both FM and LM, as can be seen from Figure 1 is "walk", followed by auto-rickshaws (both individual and shared) and then by e-rickshaws.
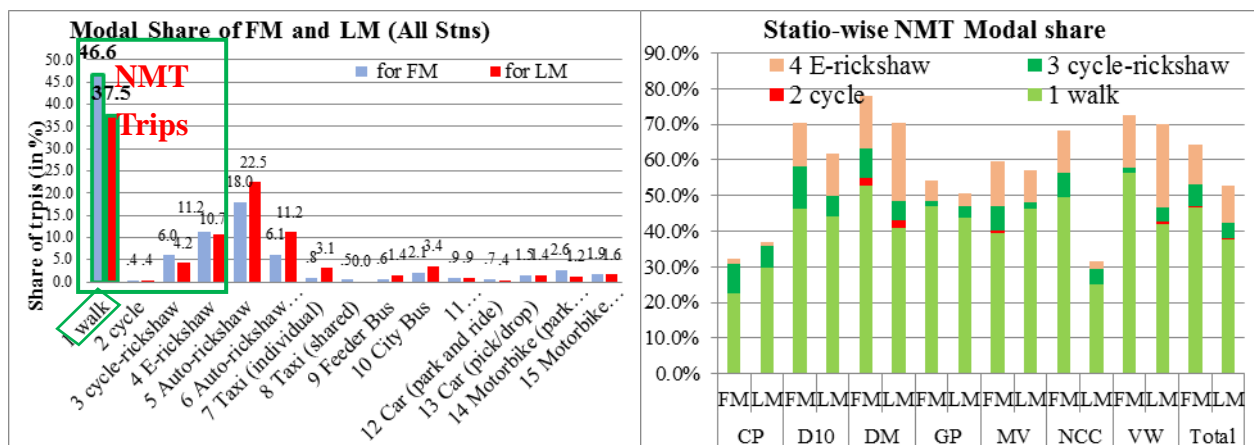

Figure 1. Modal Share of Trips (in%)

Source: Primary Survey, 2017

Use of NMT is higher for FM trips (64.1%) compared to LM trips (52.8%). Similarly there are higher share of walk users in FM (46.6%) in comparison to LM (37.6%). 62% of FM trips have origins at home-end while only 33% of LM trips have destinations at home-ends. Amongst the stations, DM and VW have the highest shares of NMT trips both for FM & LM. All stations have almost equal share of NMT trips except for NCC which may be on account of the large number and good frequency and coverage of motorised intermediate public transport (IPT) options available at the station. It is observed that 38% of users walk at both ends. Of all those who walk the FM, 21% use auto-rickshaw, 10.4% use shared auto-rickshaw and 12.4% use e-rickshaw for the LM.

Non-parametric Pearson's Chi-square test was applied to test the null hypothesis that FM/LM trip choices do not vary with station typology. Results showed the relationship between two variables as significant (the values being 0.000), thereby rejecting the null hypothesis. Similarly for the next null hypothesis, i.e., there is no relationship between the type of mode used for FM and for LM, significance test result is 0.049 which is just about significant for a critical value of 0.05.

4.2 Impact of Socio-Economic Characteristics on Modal Choice of Users

Chi-square test is also used to examine the relationship between walk as a mode used for FM & for LM against several socio-economic characteristic of commuters. As can be seen from Table3 all variables are significant for LM commute whereas variables such as occupation, marital status, age category, trip purpose and trip frequency are not significant for FM commute.

Table 3. Significance Test Results for "Walk" Mode against Socio-Economic Variables

Sl. No.	Categorical Socio-economic Variables versus Mode Choice	Pearson Chi-Square Asymp. Sig.(2-sided)
1	Gender * Mode1(walk) used for FM	.004
2	Gender * Mode1(walk) used for LM	.009
3	HH Income Category * Mode1(walk) used for FM	.000
4	HH Income Category * Mode1(walk) used for LM	.000
5	Occupation * Mode1(walk) used for FM	.305
6	Occupation * Mode1(walk) used for LM	.000
7	Marital Status * Mode1(walk) used for FM	.133
8	Marital Status * Mode1(walk) used for LM	.000
9	Vehicle for Personal Use * Mode1(walk) used for FM	.000
10	Vehicle for Personal Use * Mode1(walk) used for LM	.009
11	Age Category * Mode1(walk) used for FM	.515
12	Age Category * Mode1(walk) used for LM	.000
13	Trip Purpose * Mode1(walk) used for FM	.593
14	Trip Purpose * Mode1(walk) used for LM	.000

15	TrpFrq * Mode1(walk) used for FM	.125
16	TrpFrq * Mode1(walk) used for LM	.000

Source: Primary Survey, 2017

Gender and Household income categories are both significant variables in walk choice for FM as well as for LM. A closer scrutiny of data indicates that men walk equally at both ends of the trip whereas women prefer an IPT to cover the LM. Share of single users walking the last mile is higher compared to married ones.

4.3 Impact of Last Mile Trip Characteristics on Modal Choice of Users

90 percentile of FM and LM trips for walk trips are within 1 and 1.5 kms indicating users are willing to walk greater distances at destination ends. The mean trip lengths of all modes combined for FM & LM are 1.6 & 2.0 kms respectively; the same for walk trips are observed as 0.6 & 0.8 kms respectively.

4.3.1 Case Station Specific FM/LM Trip Characteristics

The first and the last mile covered specifically at the case stations are separated out as the physical and operational environment of the other end station (which are not part of the study) is unknown. The key FM/LM trip characteristics of the case-stations are represented in Figure 2.

The modal share of walk trips indicates that except in the case of MV where the walk share of FM trips is quite less compared to LM trips (36% vis-à-vis 53%) and in GP and DM where the shares are almost equal, all the remaining stations exhibit higher walk trips for FM. Since large number of non-motorised and motorised IPT options are available right at the station exit points, users find it more convenient to take a mode compared to walking. On the other hand, at the origin end, users generally have to first walk some distance before they can access an alternate mode and hence may prefer to cover the rest on foot. The mean ATL of all stations combined is also lower for FM than for LM (0.76 and 0.88kms respectively) and this probably also explains higher share of walk trips for FM. The walk ATLs for most stations (except for NCC) are higher for LM trips.
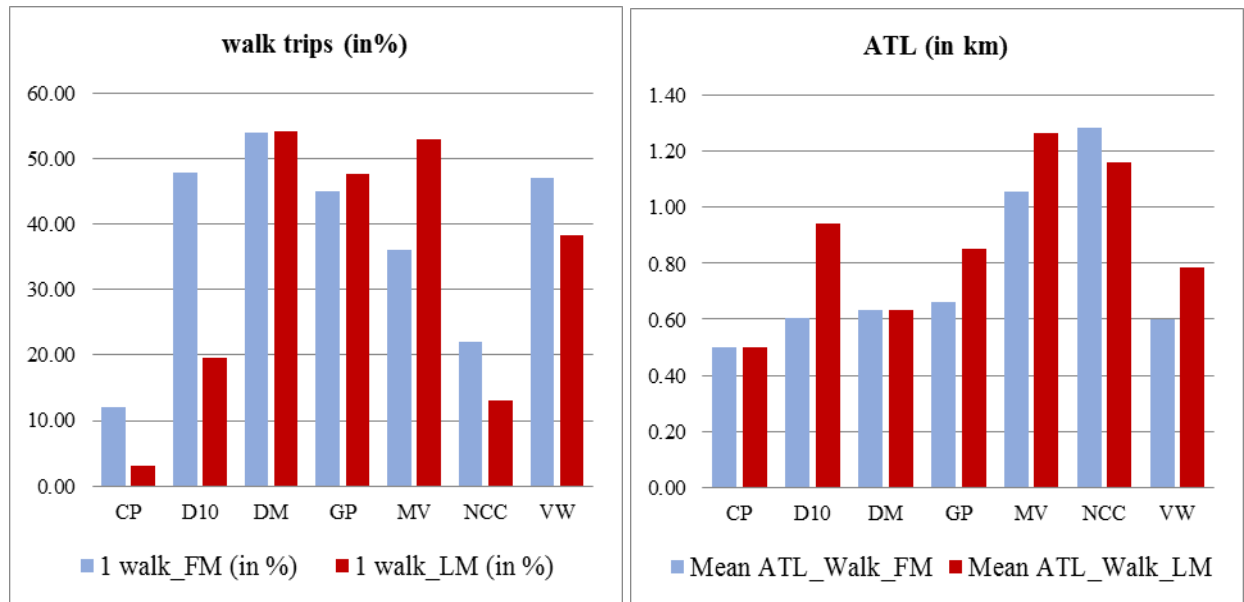
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Figure 2. FM/LM Walk Trip Characteristics of Case Stations

Source: Primary Survey, 2017

67% used NMT in FM for return home trips followed by 66% for work trips. The highest share of NMT trips for LM is for shopping (87%), followed by education (63%), recreation (54%). Lesser share of NMT trips is observed for work/business and return home purposes at the LM. Highest share of walk trips in FM are for business (62%), education (50%) and work (47%) whereas for LM, highest shares are for shopping (78%), social (40%) and work (39%). Home as trip-end origin (FM) is observed to be 62% and home as trip-end destination (LM) is 33%.

4.4 Pedestrian Environment Index (PEI)

Pedestrian environment in this study relates to the availability and quality of infrastructure for pedestrian movement to/from stations from/to origins/ destinations within walking distance. It also takes in the dimension of the overall walking environment on these routes. The paper does not include the physical planning aspects of walkability: landuse mix, network pattern and route directness, topography, etc.; however it does consider aspects that are direct derivatives of physical environment such as nature of activities, presence of obscure nooks/stretches, eyes on the street. Weighted factor method is used to arrive at scores for each indicator of overall PEIs. Twelve attributes representing two broad categories of "Infrastructure" and "Route Environment" with corresponding indicators are shown in Table 4. Each of these attributes and their sub-attributes (for e.g., attribute 9 "safety" has sub-attributes such as "threat from adjacent traffic", "obscure areas", "presence of nuisance activities", "eyes on the street", "adequate lighting at night") have been assigned scores based on either how well or poorly they meet the norms and standards or on a 5 point Likert scale rating for qualitative sub-attributes. All scores are on a maximum scale of 5 with 1 signifying very poor and 5 very good. The weights have been assigned based on users' stated preference of criteria for walk environment

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(derived from percentage of respondents identifying a particular attribute as important and their stated ranking of those attributes). P_is for each attribute and station are the weighted scores and the final PEIs represent converted percentage scores as indicated in the formula in the table.

Table 4. Attributes and Pedestrian Environment Index [PEI]s for Case Stations

Categories	Indicators	Attributes i	Weight	CP	D10	DM	GP	MV	NCC	VW
							Weighted Scores			
				P_i	P_i	P_i	P_i	P_i	P_i	P_i
	Availability	Footpath 1	80	76.8	56	48	67.2	57.6	56	76.8
		Crossing 2	70	21	56	35	44.8	32.2	42	53.2
		Wayside amenities 3	40	18.4	24	20	23.2	24	20.8	32
Ped Infra	Condition & Quality	Obstructions 4	50	35	40	15	30	26	34	45
		Surface 5	60	44.4	42	24	39.6	31.2	37.2	42
		Universal Accessibility 6	30	16.2	18	6	19.2	12.6	15.6	25.2
		Ease of Crossing 7	90	36	81	54	36	54	18	36
	Continuity & Connectivity	F.P Continuity 8	60	31.2	24	24	37.2	32.4	45.6	60
Route Quality		Safety 9	90	64.8	54	72	72	90	63	90
	Placemaking	Activity & liveliness 10	80	40	51.2	80	60.8	75.2	64	76.8
		Crowdedness 11	60	48	48	48	45.6	57.6	45.6	57.6
		Aesthetics 12	50	23	40	20	23	40	28	40
			760	455	534	446	499	533	470	635
			100	**59.9**	**70.3**	**58.7**	**65.7**	**70.1**	**61.8**	**83.6**

$$[PEI]_s = \sum_{1}^{12} P_i \ [\text{max: 100 pts}]$$

walk_FM (in %)				12.0	48.0	54.0	45.0	36.0	22.0	47.0
walk_LM (in %)				3.10	19.6	54.2	47.6	52.9	13.0	38.3
Mean ATL_Walk_FM				0.50	0.61	0.64	0.66	1.06	1.28	0.60
Mean ATL_Walk_LM				0.50	0.94	0.64	0.85	1.27	1.16	0.78
Mean ATL_Walk_All modes_FM				1.80	1.33	1.37	1.57	1.89	3.22	1.07
Mean ATL_Walk_All modes_LM				2.31	2.00	1.37	1.63	1.91	3.41	1.26

Source: Primary Survey, 2017

Note: Refer to Table1 for Station Codes

Station VW has the best overall PEI amongst all stations, followed by D-10, MV, GP, NCC. The worst PEI is for CP followed by DM. Except for DM, almost all stations have their corresponding modal walk shares in-sync with the PEIs. In case of NCC, a low share of walk trips may be attributed to the fact that the overall ATL for all modes combined is much higher than what may be considered as

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walkable distance. Additionally, NCC has the largest number and good frequency of last mile mode choice options available at the station.

Table 5 shows the relative ranking of case stations in terms of key indicators and attributes of pedestrian environment. VW performs well consistently in almost all attributes and also has a fair share of walk as FM/LM but doesn't have the highest walk shares. This may be a result of easy availability of IPT modes, similar to NCC.

Table 5. Performance Ranking of Stations for Key Indicators

Rank	Pedestrian Infrastructure			Route Quality			PEI
	Availability	Condition & Quality	Overall	Continuity & Connectivity	Placemaking	Overall	
	P_{1-3}	P_{4-7}	P_{1-7}	P_8	P_{9-12}	P_{8-12}	P_{1-12}
1	VW	D10	D10	VW	VW	VW	VW
2	D10	VW	VW	NCC	MV	MV	D10
3	GP	CP	GP	GP	DM	NCC	MV
4	NCC	GP	CP	MV	GP	DM	GP
5	CP	MV	MV	CP	NCC	GP	CP
6	MV	NCC	NCC	D10	D10	D10	DM
7	DM	DM	DM	DM	CP	CP	NCC

Source: Primary Survey, 2017

CP doesn't score that poorly in terms of pedestrian infrastructure availability, it lags behind in terms of condition and quality of infrastructure and mostly in terms of route quality (both in terms of continuity and in placemaking) of the pedestrian network emanating from metro station to destinations within walkable range. Its PEI has direct impact on the modal share of walk trips, both for FM and for LM. The station also has the lowest walk ATLs for FM and LM amongst all stations, indicating that commuters are less willing to walk in a non-conducive or uninviting environment.

In MV, with the third highest PEI, the walk share for FM is much lower compared to LM. Of all stations it is located in almost a purely residential area in a planned sector and time is more of a priority in the FM. MV also has the highest average walk trip length for the LM (more than 1 km), despite the fact that this station has the second highest share of commuters in HH income category in the second highest income bracket. This paradox may be explained by its good overall PEI as well as in terms of its second rank in "placemaking" and "route quality".

The significance of "placemaking" is reiterated in Dwarka Mor which despite performing almost the lowest in terms of all other aspects, scores better in "placemaking" and has higher share of walk trips.

5. Conclusion

It can be seen from the present study (2017) that firstly, the popularity of NMT (64% for FM and 51% for LM) as the last mile option is on the decline: 82% walked or used a cycle-rickshaw in 2008 (Gupta, Agarwal, 2008), 79% walked or used a cycle rickshaw for covering the first and the last mile in 2010 (Chidambara, 2010). Out of this only 47% and 38% walk the FM and LM respectively.

The paper concludes that the overall walkability environment offered to transit commuters is crucial in the share of walk trips for FM/LM commute. It also influences the distance commuters are willing to walk. The findings derived from Chhatarpur and Mayur Vihar station clearly indicate that it is not sufficient to provide just pedestrian infrastructure but aspects of safety (both actual and perceived), activity and liveliness, eye on the street and appeal of the entire pedestrian network surrounding the stations is crucial in commuters decision to opt for a sustainable last mile option such as "walk". The case of MV also indicates that good walk environment can stimulate commuters to walk longer distances (1.2 km was walk ATL for LM).

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