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Urban Mobility: An Understanding of Critical Success Factors of Multimodal Passenger Transport in India and Research Implications

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Abstract

Cities matter. They are the engine of the global economy and are already home to more than half the world's population. Passenger mobility in cities is now an important area of research in Decision Sciences and Analytics. For the urban passenger, the connectivity at the last mile with the dominant public transit system in a city has assumed critical significance. This paper aims to identify key issues related to adoption and usage of modern public transport systems in urban India. We see significant opportunities in building on from existing frameworks for solving well-known problems in shared mobility, to use a complementary approach and enhance sustainable multimodal passenger transport across urban geographies.

Keywords: Public Transit, Shared Mobility, Last Mile Connectivity, Sustainable Transport

1. Introduction

Population growth and urbanization across the world are driving significant changes in urban mobility. 54% of the world's population lives in cities and accounts for 80% of world GDP *[Savelsbergh et al, 2016]*. It is projected that by 2050, 66% of the population will be urban, and is expected to touch 85% by 2100. Mega-cities (population of 10 MM or more) across the world are growing in both population and economic activity. India is already seeing this extensively through an expansion of administrative jurisdiction of cities like Chennai, Bangalore, Hyderabad, Ahmedabad and Pune. India's own urban population is projected to double to 0.9 Bn by 2050 *[World Urbanization Prospects, UN 2018]*. The associated increase in population density over a wider area will present unique and diverse challenges in passenger mobility which is the primary focus of this paper.

The increasing importance of the "sharing" economy is a significant driver in passenger mobility. This is in contrast to freight transport, where the need for faster and more reliable mobility solutions is largely being driven by e-commerce. Digital connectivity and big data being available real-time through mobile devices and platforms are seen as clear enablers in the future *[Savelsbergh et al, 2016]*. We are also witnessing the development of modern public shared transit systems in the megacities via Metro Rail projects and high-speed rapid transit systems like BRTS, Monorail etc. in emerging economies like India. Simultaneously, there has also been a trend of strong adoption of private shared mobility services provided by Transportation Network Companies such as Uber and Ola, impacting usage of public transit systems, such as indicated in *[Acheampong et al. 2020]*. This has led to some conjecture of a possible eventual decline of public transit systems. However, there is significant literature which points out otherwise. In fact, *[Currie, 2018]* maintains that private shared mobility itself comes with its own challenges of occupancy, sustainability and scale. At the same time, it is also interesting to note that public transit systems like the Metro infrastructure operating in urban India have also met with challenges across multiple fronts.

This is where we believe a complementary approach to the development of public transit facilitated by shared mobility will benefit the urban passenger, while sustainably addressing the above intrinsic challenges. A deeper look at the prevailing conditions and expected trends over the medium/long term is presented in the next two sections.

2. Evolution Of Urban Transport

[Jones, 2014] has traced the evolution of urban transport from a policy perspective over the last fifty years across three stages as illustrated in Figure 1.

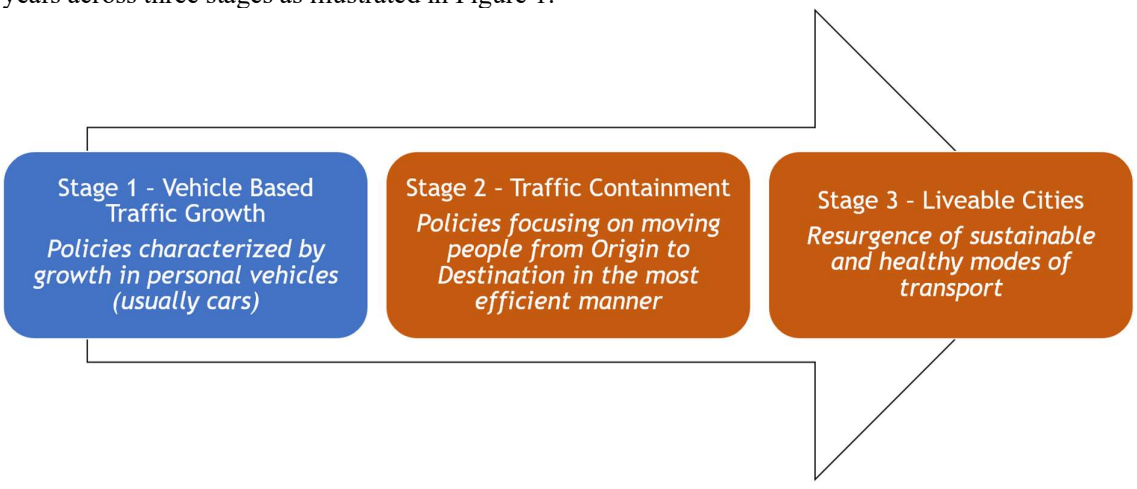

Figure 1: Evolution Of Urban Mobility (Jones, 2014)

We may look at the current situation in urban India as largely passing through the second stage where the focus is still on moving passengers from origin to destination in the most efficient way possible through a combination of public and private transport. The urban metro rail infrastructure has seen a significant push from the Government of India with investments in excess of INR 2 Tn, across more than 20 cities as per *[WRI Report, 2018]* under the National Urban Transport Policy (NUTP). The stated objective is to build and deploy mass rapid transit systems in all cities of population 1 MM or more. We highlight the plans on some of the major projects in Table 1 below. In the context of this evolution we would like to bring in the notion of "Compressed Change" as defined by *[Chandy et al, 2016]* as a significant phenomenon at play, where emerging markets mimic macro trends seen in developed countries, except that the latter development leapfrogs over time and milestones. Indeed, the vision document of NITI Aayog *[Moving Forward Together, 2018]* itself projects a transition to shared mobility

Name	Current Operational Length (km)	Operational Since (Year)	Planned Additional (km)	Number of Stations
Delhi Metro	389	2002	145	250
Hyderabad Metro	69	2017	67	57
Chennai Metro	64	2015	145	140
Bengaluru Metro	48	2011	230	46
Kolkata Metro	38	1984	120	33
NOIDA Metro	30	2017	15	22
Kochi Metro	26	2019	15	22
Nagpur Metro	25	2019	112	5
Lucknow Metro	23	2017	150	21

Table 1: Metro Rail Infrastructure in India (as of December 2020)

the extent of 50% of passenger kilometres by 2040, cutting short the era of personal vehicle ownership as seen in developed markets. As a result, we are also simultaneously seeing early indications of moving to the third stage of sustainable transport in more developed states like Karnataka, where policies to encourage healthier modes of transit such as public bike sharing in Bengaluru and Mysore *[BPAC/Uber Report, 2020]*, are already being experimented with in an effort to improve ridership.

3. Understanding Shared Mobility

Shared mobility may be defined as the shared use of any motor vehicle, bicycle, or other low speed transportation mode, and is now one of the ubiquitous facets of the sharing economy *[Shaheen et al, 2016]*. Shared mobility enables users to obtain short-term access to transportation as needed, rather than requiring ownership. It could include carsharing, personal vehicle sharing (i.e., P2P carsharing and fractional ownership), bikesharing, scooter sharing, ridesharing, and on-demand ride services. Alternative transit services, such as shuttle services, paratransit, and microtransit, supplement fixed-route bus and metro rail services. Shared mobility also includes ridesourcing (sometimes referred to as ridehailing as well) via Transportation Network Companies or TNCs, such as Ola and Uber; ridesplitting (e.g., UberPOOL) in which passengers split a fare and ride; and e-Hail (app-enabled taxis). *[Shaheen & Chan, 2016]* have developed a basic framework for understanding the variety of ways in which shared mobility could operate, as shown in Figure 2. The key definitions have been included in the Glossary for reference.

Mobility can be shared either by sharing the vehicle itself, or by sharing individual rides. Modern technology allows various was in which either can be accomplished. Some of these, such as ridesharing, bikesharing, carpooling etc. have been better accepted for a variety of socioeconomic reasons across the world, while other concepts are popular in respective niches. We believe that combinations of some of these models of shared mobility hold the key to solving the problems of access and efficiency for the urban passenger. *[Shaheen et al, 2016]* also note that an increasing body of empirical evidence indicates that shared modes can provide numerous transportation, land use, environmental, and social benefits

leading to better sustainability. This has been extensively observed in cities in the US in multiple research studies on carsharing and bikesharing.

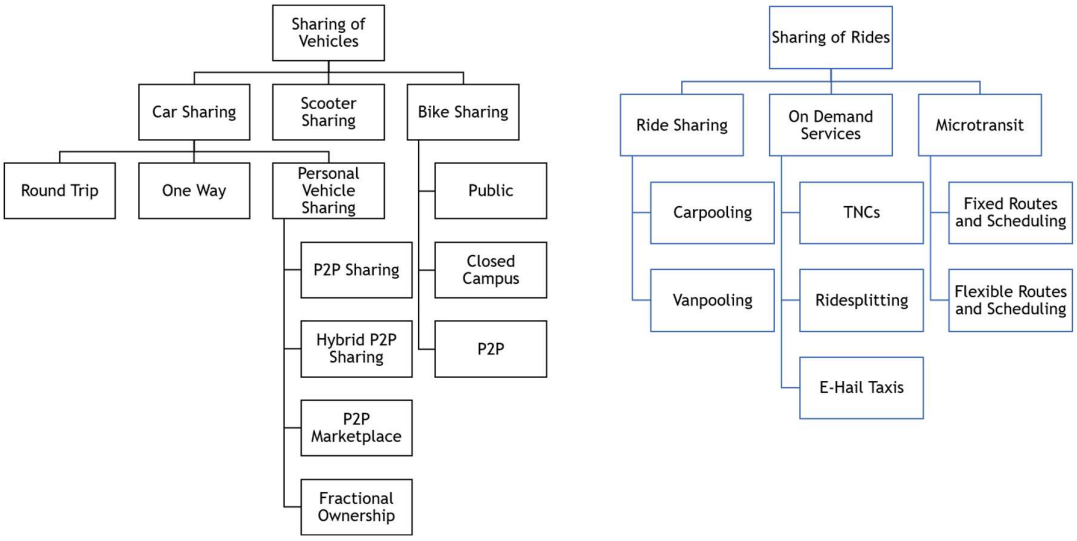

Figure 2: Shared Mobility *(Shaheen and Chan, 2016)*

4. Public Transport and Shared Mobility - The Opportunity

Given this background, we want to take a deeper look at the interaction between the public transport and shared mobility, where some of the pertinent research questions we need to answer are:

- What are the challenges and opportunities faced by these two ecosystems in India and how do they interact with each other?
- What are the significant overarching passenger insights emerging from a deeper understanding of the interaction between these ecosystems?
- What should be some of the key focus areas for academic research from a problem solving perspective?

5. Analysis and Discussion

I. Key Insights

There are several perspectives we need to build around the coexistence of Public Transport with Shared Mobility which can help us build a framework for building solutions to the problems of urban mobility in India.

(a) *Complementary Sustainability*

A key insight that has been demonstrated in research is that the overall growth of Public Transport in conjunction with Shared Mobility can reduce personal vehicle usage while driving sustainable urban economic activity. *[Tirachini 2020]* has done an extensive review of the impact of ridesourcing on the use of public transport. There is ample evidence across countries to believe that multi-modal travelling is a significant phenomenon and which varies with the strength of the public transport network in the city. This is in spite of sporadic trends of a temporary decline in usage of public transit as shared

mobility started growing due to possible substitution effects. Various studies have also examined the specific impact of ridesourcing on vehicle ownership.

Allied to this is the assertion that mass public transit services complement shared mobility services for the urban passenger depending upon factors like the reason for travel. This is immediately observed in behaviour related to work commute, where the passenger uses public transit for the bulk of the journey with a different mode for the first-mile from the source and the last-mile to the destination. Shared mobility is additionally used for other specific occasions such as recreation, social trips etc. *[APTA 2016]*

(b) *Criticality of the Last Mile*

A very well-researched and understood insight across the globe is that public transit systems necessarily need strong, tightly-coupled last mile connectivity for the adoption and continued patronage, regardless of passenger behaviour and demographics. Case studies in India such as the failure of the Chennai MRTS as pointed out by *[Madhavan, 2010]* or the relative underperformance of the Ahmedabad BRTS as indicated by *[BRT Cases Studies - India, 2013]* amply demonstrate this phenomenon as well.

The growth of shared mobility is seen as a possible opportunity to address this issue. There are several instances of public transport systems collaborating with TNCs in developed markets which have met with varying degrees of success *[Tsay et al, 2016]*, and are being continuously improved upon. We are seeing similar trends in India already with partnerships such as in Bengaluru *[BPAC/Uber Report, 2020]*. There is also rigorous academic research around possible frameworks for public-private partnerships in urban mobility, as identified by *[Lucken et al, 2020]*, where partnerships to address constraints around first mile/last mile connectivity have been used in developing service models providing mobility solutions. In addition, recent research from *[Stiglic et al, 2018]* has demonstrated that specific cases of shared mobility, such as ridesharing, can be successfully integrated with a fixed public transit system to enhance overall mobility and increased use of public transport.

It is worth noting that experiments on improving last mile connectivity in India have yielded encouraging results albeit in very limited scope. This has been demonstrated by *[WRI Report, 2018]* in the case of the Bengaluru Metro under the Station Access and Mobility Program (STAMP), which evaluated pilot carpooling and bikesharing initiatives at the last mile in Baiyappanahalli. *[Kathuria et al, 2019]* reported a positive effect of good walkability indices for roads leading to BRTS bus stations on overall ridership in the case of the Ahmedabad BRTS.

(c) *Economic Affordability*

The last major factor we believe to be critical in India is the economics and affordability of transport for the urban passenger. In the Indian context, affordability needs to be looked at from the perspective of the contribution of transport to the basket of daily spends of the citizen – this tends to be higher than in developed nations and leads to greater price elasticity. An average trip on the Delhi Metro for example could cost upto 20% of the daily earnings of a minimum wage worker. This is much higher than global benchmarks of about 10-15%. Recent research at the Centre for Science and Environment [CSE Research, 2018] has already demonstrated severe limitations on the ridership of existing Metros/BRT systems due to fare structures being out of sync with the willingness of the passenger to pay. Delhi metro, for example, actually witnessed a decline in ridership when it revised prices upwards in 2017-2018. We know that, there has been considerable academic interest around pricing strategies for ridesourcing as a specific instance of shared mobility. Multimodal pricing structures, policies and execution add a layer of complexity for the passenger but will also present the opportunity to improve overall end-to-end affordability. This will depend very closely on city geography and demographics.

II. Preliminary Understanding *(Pilot Study)*

To develop a preliminary understanding of the Indian context, we conducted a pilot survey amongst current users of the Bangalore Metro services in November 2021. The online survey reached out to residents of Bengaluru who have used in the city's metro rail services, and captured stated responses to questions around their travel behavior with respect to the metro rail and associated first/last mile connections as well. Summary data has been shared in charts in *Appendix 3* – we try to capture some of the basic findings below.

- Currently the metro rail system in Bangalore (which is still largely work-in-progress) is the least preferred mode of transit – however, the differences are not stark as highlighted in Figure 4.
- We also see that the first/last mile leg of the journey is felt to be relatively more expensive by travelers in relation to the metro ride, as illustrated in Figure 5.
- Even within station infrastructure, accessibility facilities assume greater significance than regular amenities. Proximity to the metro station is seen to be a significant driver for current users with easy access to ridehailing services being sought after over other modes (Figure 6). This is central to our theme of complementary sustainability as well.
- Bangalore Metro being in early stages of operation with large sections still under development, current passengers are primarily occasional users of the system; however early indications are that work commuters behave significantly differently in their usage, as highlighted in the charts in Figure 8.
- In addition, there are also emerging trends of passengers appearing to have different preferences between their access and egress options, which results in different times of travel across the first and last mile, as illustrated in Figure 9.

III. Implications for Research

Drawing from the insights summarized in the Section 5(I) and results from the pilot study, we believe the following areas need to be looked into with some analytical rigour from an academic perspective with collaboration from key public transport entities.

(a) Metrics and Standards

Metrics and standards for last mile connectivity of a fixed public transit operation such as Metro, BRTS, Monorail etc. While there has been some work around evaluating multimodal last mile accessibility in specific cases such as the Delhi Metro as identified by *[Ann et al, 2019]*, there is a clear lack of understanding of what defines good last mile connectivity from a passenger perspective in urban India. Indeed, some of these nuances have been highlighted in our pilot study as well (ref. Appendix 3). Research around sustainable passenger metrics for evaluating last mile connectivity will help address this gap. For instance, *[Venter, 2020]* provides directional ideas around this from their technique tested on the Gautrain system in South Africa.

(b) Pricing

End-to-end pricing strategies for an integrated multimodal passenger transit system optimizing overall socio-economic benefit will need to be developed that can be adapted for various instances. Historically, literature on pricing has focused on dynamic pricing and congestion pricing in transportation networks. While there has been some recent research on pricing in related areas such as fixed rail networks and airlines such as *[Zhang et al, 2017]*, these look at objectives only from a firm revenue management perspective. In addition, there is not much work around pricing in the domain of flexible multimodal systems. Our pilot study, for example, indicates that the last mile transit is possibly seen as less affordable in the Indian context. We believe there is significant potential to build on strategies from more relevant versions of the LMTS pricing problems such as those dealt with by *[Chen et al, 2018]* in the case of the widely used Singapore MRT.

(c) Capacity Management

Dynamic capacity management, scheduling and routing of last mile transit and feeder systems has been an area of interest in operations research. We believe that existing research around well-established problems can be significantly leveraged further and adapted for the Indian context. *[Mourad et al, 2019]* have done an extensive survey on independent shared mobility systems and specific problems that have been solved in this area. Table 2 lists the major relevant areas in passenger transport which we will need to draw from, depending on the nature of the last mile connections specific to the public transit system being studied. Detailed definitions of these problems have been shared in the Glossary of terms at the end of the paper.

Problem Variant	On Demand	Daily Commute	Long Distance	Pre Arranged	Real Time
Carpooling		✓			
Flexible Carpooling		✓	✓	✓	✓
Vanpooling		✓		✓	
Pre-Arranged Ridesharing		✓	✓	✓	
Dynamic Ridesharing	✓				✓
DARP	✓			✓	✓
Shared Taxi	✓				✓

Table 2: Shared Passenger Mobility Problems (Mourad et al 2019)

6. Conclusion

The paper draws from existing research to uniquely highlight that the ecosystems of public transit and shared mobility complement each other and can be sustainably leveraged to enhance urban passenger mobility. Based on our analysis, we establish some critical success factors for the continued growth of urban passenger mobility in India. We finally use these success factors to identify possible research directions in analytics.

Acknowledgment

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Appendix 1 - Glossary of Terms

Carsharing

Carsharing is a car rental service in which people who are interested in making only occasional use of a vehicle can rent cars for short periods of time. Through carsharing, individuals can gain the benefits of private vehicle use without the cost and burdens of ownership (e.g. fuel, maintenance, insurance). Carsharing members instead are able to access a fleet of shared vehicles on an as-needed basis and pay a usage- and/or membership-based fee. A variation of car-sharing seen in some European and US cities is scooter sharing over one-way or roundtrips.

Bikesharing

Bikesharing systems allow users to access bicycles on an as-needed basis from a network of unattended stations, typically concentrated in urban areas. Most bikesharing operators are responsible for bicycle maintenance, storage, and parking costs. Bikesharing can also be freefloating within a geo-fenced area either through a business-to-consumer (B2C) operator or through P2P systems enabled through third-party hardware and applications. Most bikesharing systems have been public, and accessible for paying customers.

Ridesharing

Traditional ridesharing facilitates shared rides among drivers and passengers with similar origin–destination pairings. Traditional ridesharing includes vanpooling (the grouping of seven to fifteen persons commuting together in one van) and carpooling (groups of seven or less travelling together in one car), which have been in use for decades. In Prearranged ridesharing , travelers' demand (drivers and riders) is known beforehand (i.e. travelers' origins, destinations, and departure and arrival times are given in advance) and can thus be used to plan their shared trips. Dynamic ridesharing focuses on matching drivers and riders on-the-fly. In other words, new drivers, offering rides, and riders, requesting rides, can enter and leave the system at any time, and the system then tries to match their trips at short notice (or even en-route).

Ridesourcing

Ridesourcing refers to services by TNC (Transport Network Companies) that use smartphone apps as platforms to connect community drivers with passengers. There are various terms used for this now ubiquitous transportation option – ridesourcing among transportation academics, and ride-hailing and ride-booking among the popular press. Examples of these services include Lyft, Uber, Ola etc. A key principle to note here is that the TNC providing the platform controls the end-to-end pricing of the ride and the share of the parties involved.

Ridesplitting

Ridesplitting is a variation on ridesourcing: it involves splitting a ride and fare with someone else taking a similar route. Usually these are operated by ridesourcing TNCs as a supplementary service for a different segement of passengers. These shared services enable dynamic route changes, as passengers request pickups in real time.

Microtransit

This is a recent form of private transit enabled largely by smartphone technology. Microtransit operators primarily target commuters, connecting residential areas with urban and suburban job centres, with medium capacity vehicles. Microtransit services can operate both under fixed and flexible paradigms, varying by demographic conditions. Examples include Bridj, Via, Chariot in different cities in the US.

e-Hailing

e-hailing is the taxi industry's version of ridesourcing with their own mobile device apps. Travellers can use 'e-Hail' apps of specific taxi companies to hail a taxi electronically via their smartphones; the apps are maintained either by the taxi company usually in collaboration with a third-party tech provider.

Carpooling and Vanpooling

Carpooling was first introduced by large companies in an effort to encourage their employees to pick up colleagues while driving to/from work. The idea was to minimize the number of cars traveling to their sites every day. Carpooling was generally used for commuting but has become increasingly popular for longer one-off journeys. The carpooling problem aims to determine the subsets of travelers that will share the same trip and the paths these shared trips should follow in order to maximize sharing and minimize travel costs. In vanpooling, commuters in the vanpool drive to an intermediate location, called a park-and- ride location, and then take a van and ride together to the target destination. Car/Vanpooling can be operated on daily or long-term bases, provide regular and cost efficient means of transportation, but do not accommodate unexpected changes of schedule.

DARP

Dial-a-ride Problems (DARP) seek shared trips between any origin and destination in response to advanced passenger requests within a specific area. The DARP models a demand-responsive transportation mode in which the aim is to define a set of routes in order to satisfy passenger requests at minimized overall operating costs.

Shared Taxi

In the shared-taxi problem, passengers indicate their desired pickup and drop-off locations, their earliest/latest acceptable pickup/drop-off time, and a maximum trip time. Solving the shared-taxi problem aims to optimally assign passengers to taxis and determine the optimal route for each taxi, while minimizing response time.

Appendix 2 - Pilot Survey Questionnaire

1. What is your age?

2. What is your Gender?

- Male
- Female
- Non-binary/Third Gender
- Prefer not to say

3. What is your annual household income?

- >= INR 1,500,000
- Between 1,000,000 to 1,500,000
- Between 500,000 to 1,000,000
- <= INR 500,000

4. What is your highest education level?

- PhD/Post-Doctoral
- Masters/MBA (Post Graduate Degree/Diploma)
- College (Graduate Degree/Diploma)
- 10+2 /Intermediate
- <= High School/Class X

5. What best describes your employment status?

- Salaried
- Self-Employed
- Student
- Homemaker
- Others

6. What area of Bangalore do you reside in?

- North
- South
- East
- West
- Central

7. Please rank your usage of the following modes of transport (1 - Most frequently Used, 6 - Least Frequently Used)

- Bus/Minibus/BRT
- Shared auto/Shared Taxi
- Regular Taxi/Ola-Uber/Call Taxis
- Metro Rail/Suburban Rail/Monorail
- Own vehicle (2-wheeler)
- Own vehicle (4-wheeler)

8. Have You travelled in Metro Rail before?

- Yes
- No

9. What best describes your current frequency of usage of Metro Rail?

- Daily
- Multiple times a week
- Multiple times a month
- Occasional

10. What is usually your main purpose for using the metro?

- Work Commute
- Business related local travel
- Travel to school/college
- Other personal local travel

11. How do you usually travel to the Metro Rail Station from your place of origin?

- I walk to the station
- I use a bicycle to the station
- I take my vehicle (2-wheeler/4-wheeler) to the station
- I use regular auto/taxi/bus to the station
- I use cab services like Ola/Uber/ Rapido etc

12. How do you usually travel to your destination after exiting from the Metro?

- I walk from the station
- I use a bicycle from the station
- I take my vehicle (2-wheeler/4-wheeler) from the station
- I use regular auto/taxi/bus from the station
- I use cab services like Ola/Uber/ Rapido etc

13. How long do you take to reach from your place of origin to the metro station usually?

- Less than 10 minutes
- Between 10-20 minutes
- More than 20 minutes

14. How long do you take to reach from your metro station to your final destination usually?

- Less than 10 minutes
- Between 10-20 minutes
- More than 20 minutes

15. How affordable are the metro rail fares? (Likert Scale 1 to 5)

16. How affordable is the journey to and from the metro station for you? (Likert Scale 1 to 5)

17. Please rank the following metro rail station facilities in terms of their importance to you (1 - Most Important, 5 - Least important)

- Parking facilities (2/4-wheeler)
- Retail shops and outlets • Walkaways, subways, escalators
- Attendant staff
- CCTV Surveillance

18. Rank the following in order of importance for your trip to and from the station to your final destination/source (1 - Most Important, 4 - Least important)

- Integrated payment with the metro (smart cards, mobile payments etc.)
- Multiple access and exit options like shared transport, autos, taxis and others
- Timely and predictable services to and from the metro station
- Proximity of the station to your place of origin or destination

19. Rank the following in order of importance for your trip to and from the station (1 – Most Important, 4 - Least important)

- Easy access to ride-hailing services like Ola, Uber, Rapido etc.
- Bicycle sharing services
- Connectivity with local bus services
- Pedestrian walkways, subways, etc.

Appendix 3 - Analysis of Pilot Survey Data

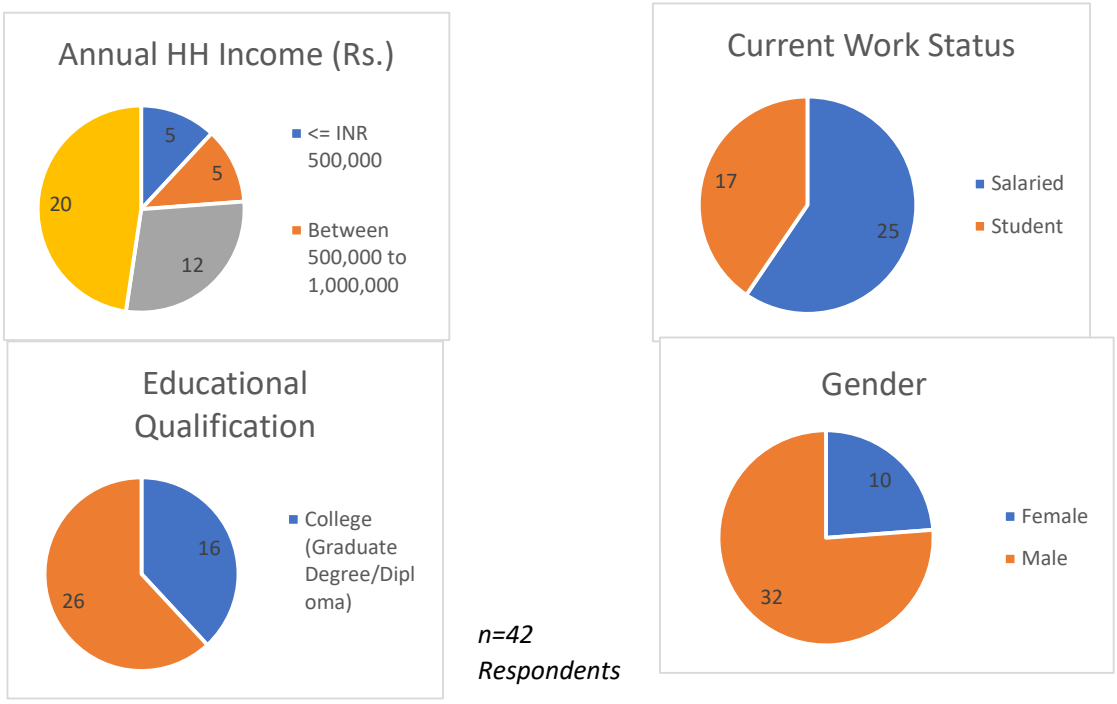


Figure 3: Demographic Profile of Survey Respondents (Bangalore)

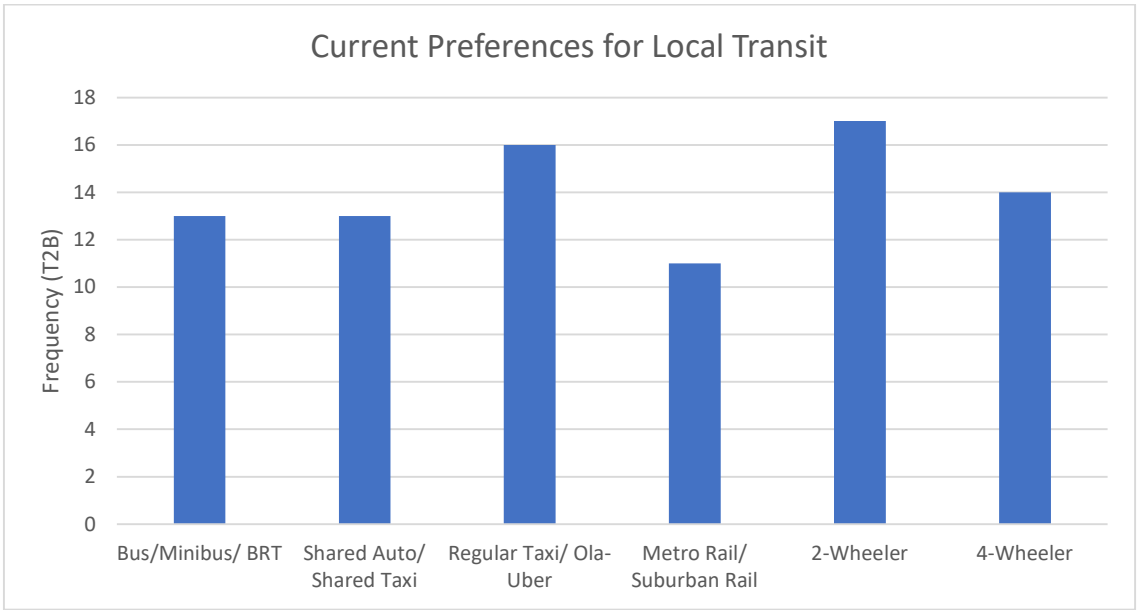


Figure 4: Current Preferences for Local Transit (Bangalore)

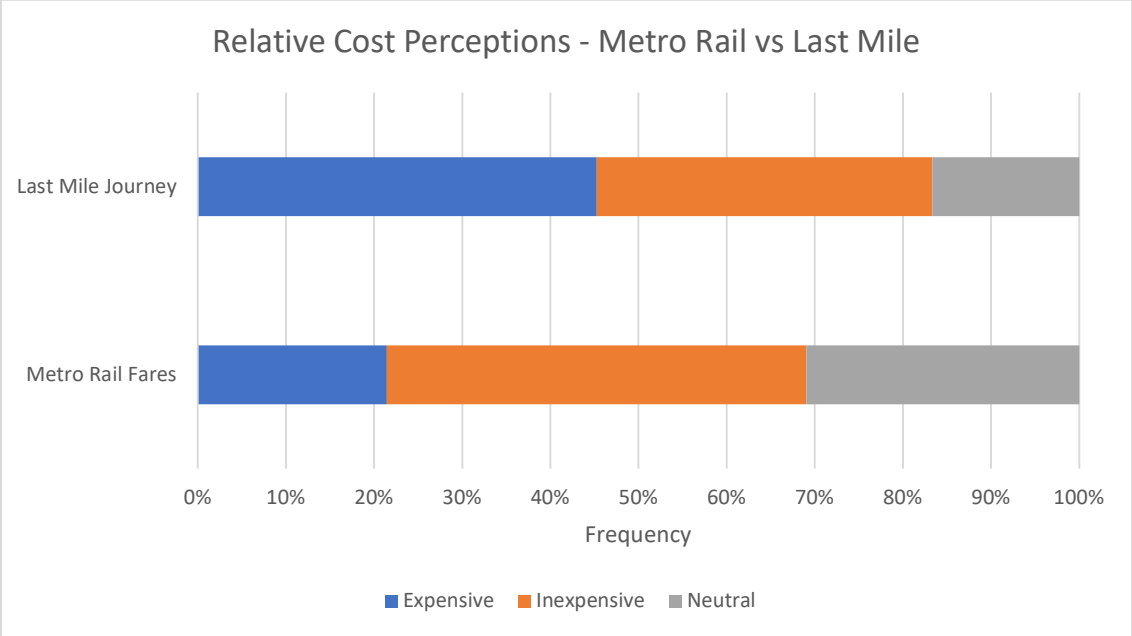


Figure 5: Affordability of First/Last Mile

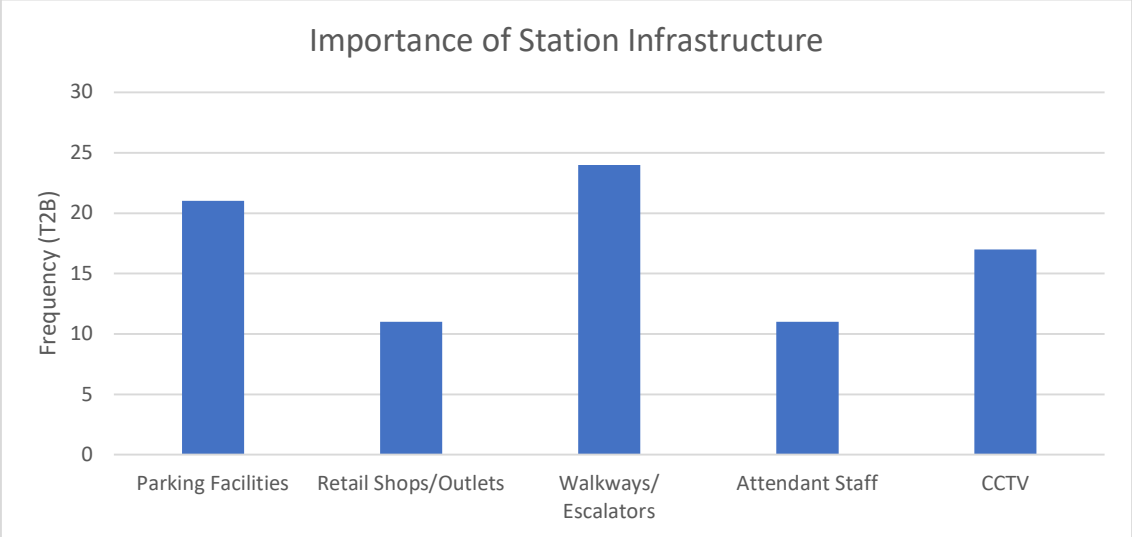


Figure 6: Station Infrastructure

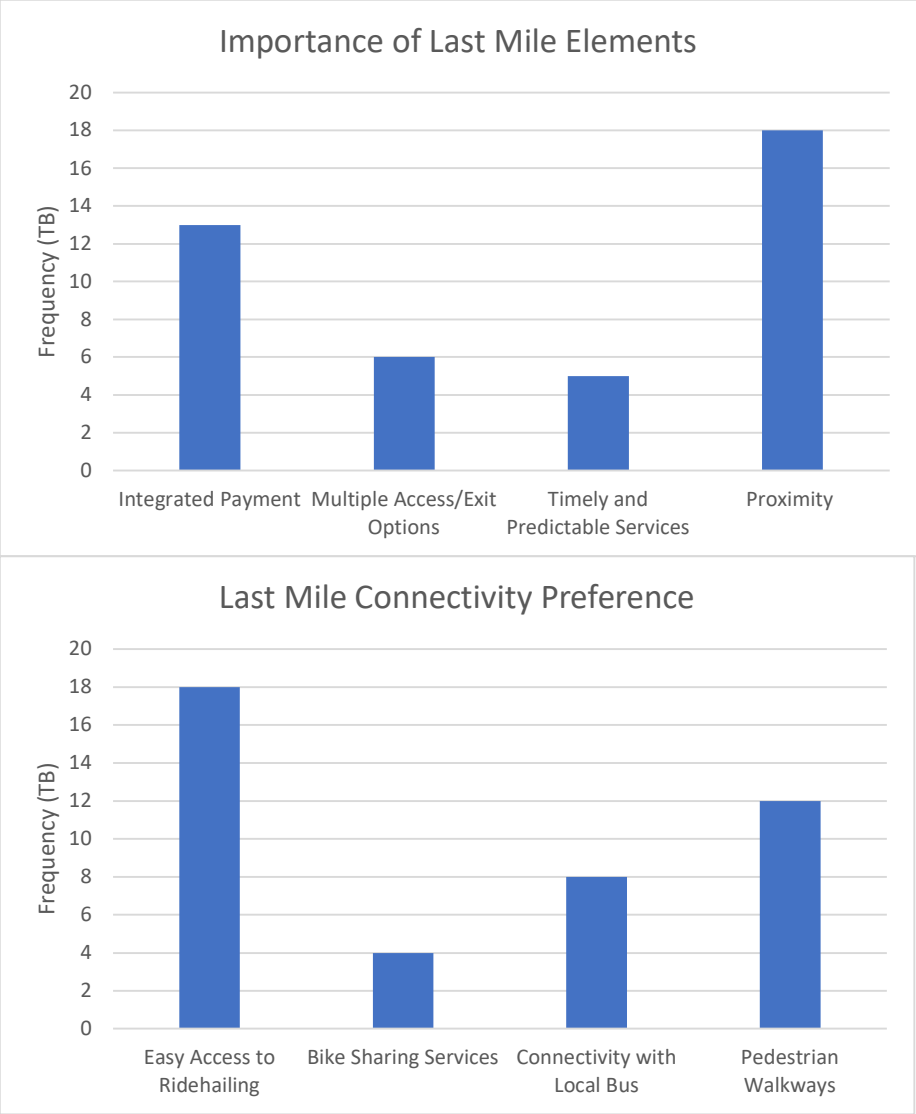
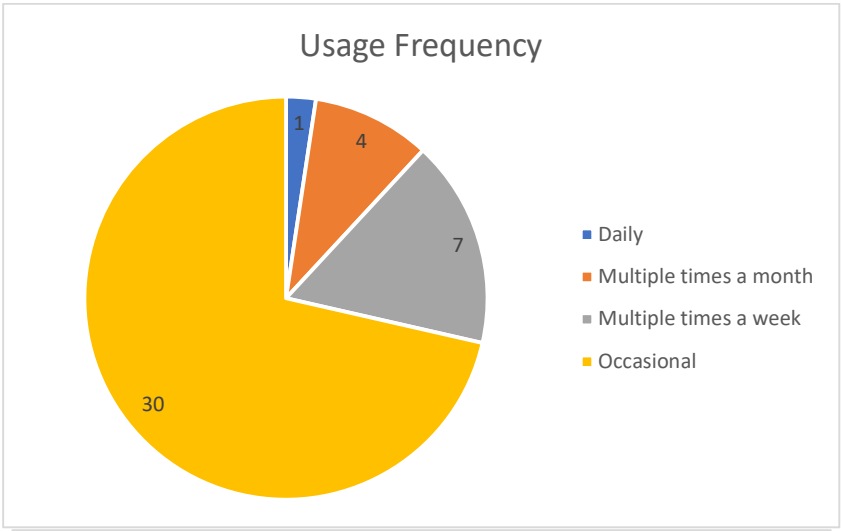
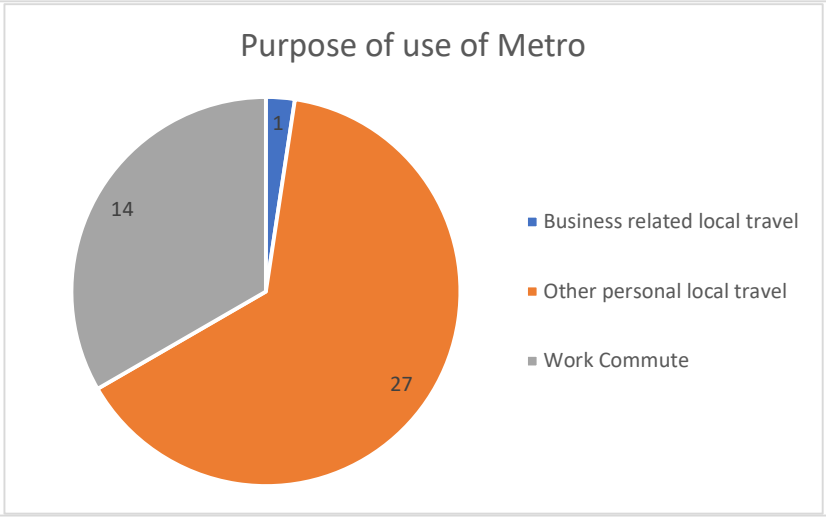


Figure 7: Last Mile Preferences





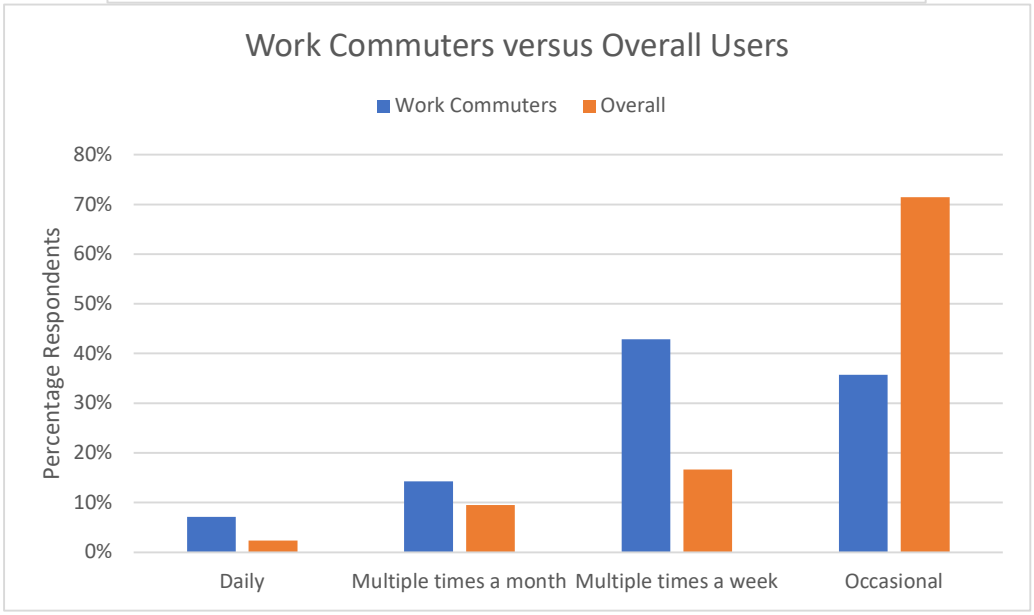


Figure 8: Work Commuters vs Ordinary Passengers

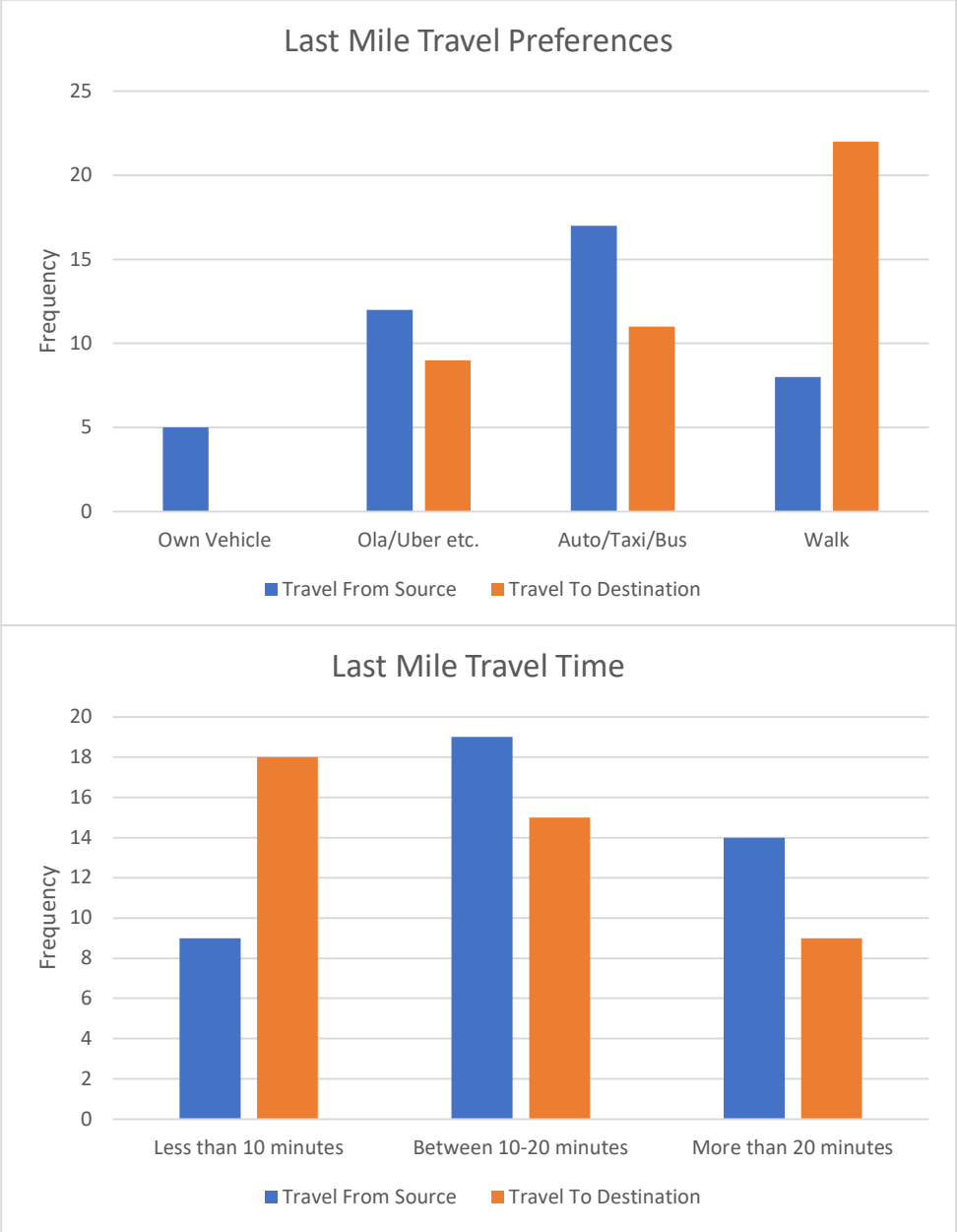


Figure 9: First/Last Mile Travel Behavior