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Leveraging innovation for last-mile connectivity to mass transit

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Abstract

Last-mile connectivity is an important factor in enabling greater integration and accessibility of mass transit networks to the largest number of urban residents. With the rise of new mobility enterprises, characterized by mobile applications delivering real-time information and on-demand and shared mobility, there is potential for integration with public and mass transit to bridge the last-mile gap. This paper presents and analyzes the results from a case study in which new mobility enterprises are piloted as last-mile solutions at a metro station in Bangalore. The solutions have a high perceived time savings among users, and it is found that there is a measurable modal shift from personal vehicles to these solutions for bridging the last mile gap. At the same time, the case study shows that there is need for supporting regulatory frameworks and greater multimodal integration for enabling public-private collaboration for seamless and sustainable urban mobility.

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Keywords: mass transit; last-mile connectivity; innovation; sustainable urban mobility; new mobility; multimodal integration

1. Introduction

India's ongoing urbanization is accompanied by rapid motorization of urban transport and a steady growth in travel demand, resulting in congestion, increased fuel consumption and sharper inequalities of access to transport. The total number of registered motor vehicles in the country has grown seven-fold over the past two decades, from 30.3 million in 1995 to 210 million in 2015 (Indiastat, 2015). At the same time, travel demand in Indian cities has risen, with increasing per capita trip rates (PCTR) and average trip lengths (IUT India & CSTEP, 2014)

Urban congestion has led to slower traffic speeds and increased commuting times, with a tremendous impact on economic productivity; it is estimated that traffic congestion cost Delhi INR 540 billion (USD 8.3 billion) in 2013

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alone (Davis et al, 2015). Congestion is also linked to higher air pollution, and a CSE study of congestion in Delhi shows that NO2 levels increase by 38% during the evening peak hour traffic (Zhang & Batterman, 2013; Centre for Science and Environment, 2017). With its higher energy demand, the transport sector is also a major contributor to the greenhouse gas (GHG) footprint in Indian cities, with contributions ranging from 13.3% in Kolkata to 56.86% in Hyderabad (Ramachandra et al, 2015).

Underlining the urgent need for sustainable urban mobility, the National Urban Transport Policy of the Government of India recommends all cities with populations of over one million inhabitants to plan for mass rapid transit systems (Ministry of Urban Development, 2014). In response, the Centre and various State governments are investing about two trillion INR (USD 31.27 billion) in building almost 900 kilometers of metro rail-based mass rapid transit systems (MRTS) across 18 cities in the country (Bhatt, 2017). At last count, about 400 kilometers of metro rail corridors are operational in ten cities, as seen in Table 1.

Table 1. Metro rail networks in Indian cities

Metro rail network	Operational length (in km)
Delhi Metro	217.90
Bengaluru Metro	42.30
Chennai Metro	27.36
Kochi Metro	13.30
Jaipur Metro	9.60
Kolkata Metro	27.39
Gurugram Metro	11.60
Mumbai Metro	11.40
Lucknow Metro	8.5
Hyderabad Metro	30.00
Total	399.35

However, metro ridership in most Indian cities continues to lag behind projected numbers, partly due to inadequate network coverage and higher fares, but also due to poor connectivity to the metro rail network. Bangalore Metro, designed for a daily ridership of 820,000 passengers, currently caters to about 400,000 passengers. A survey by the World Resources Institute, of potential metro passengers at major trip generation points around the Bangalore Metro, found that first- and last-mile connectivity pose a significant hurdle to metro usage, with 70% of respondents citing poor connectivity to the metro as a reason for not using it.

Meanwhile, technology-led innovation in urban mobility has given rise to thriving entrepreneurship in the sector, with the evolution of business models that are transforming the way mobility is delivered and accessed. From bus aggregators to carpooling solutions and parking management services, a rich ecosystem of mobility startups is focused on capturing the growing travel demand among urban commuters, and on easing the pain points of daily commuting like excessive wait times, crowded transit vehicles, and lack of information about intermodal connectivity. By integrating cleaner vehicle technologies and promoting shared mobility, new mobility enterprises also demonstrate the potential to be key stakeholders in achieving sustainable mobility.

This paper investigates the potential of technological innovations in mobility to improve the accessibility of mass transit networks for urban commuters, by analyzing findings from the Station Access and Mobility Program (STAMP), in which new mobility enterprises were deployed to provide last-mile connectivity to a metro rail station in Bangalore. The case study analysis uses operations and survey data from twelve weeks of service operations by the new mobility enterprises and finds that the services induced a measurable modal shift from private modes to shared mobility, and resulted in high perceived time savings for their users. Qualitative observations of ecosystem conditions and stakeholder networks also contribute to the analysis, and some inferences are presented on the necessary conditions for enabling the integration of public and mass transit with privately-operated new mobility enterprises. The case study adds to the nascent but growing literature on the scope and impacts of new mobility business models and technologies on the trajectories for sustainable mobility.

The next section examines the impact of last-mile connectivity on mass transit usage and the emerging research on new mobility enterprises and their effects on urban mobility. The STAMP case study is then presented, with a brief introduction to Bangalore and its metro rail network, the objective and process of the initiative, and the data from its execution. Results and analysis of the STAMP implementation are described, followed by a discussion of their implications and the future studies needed to further the research.

2. Review of literature

In transportation, first- and last-mile connectivity refer to the end segments of a journey undertaken by public or mass transit, connecting origin and destination points to stations or stops on the transit network. An aspect that has been shown to have great potential for improving the quality and level of service of public and mass transit, the provision of economical and convenient last mile connectivity is nevertheless an area that has been greatly neglected in Indian cities (Chidambara 2012). There is extensive research to suggest that lack of good connectivity between mass transit stations and the end points of commutes may dissuade commuters from using public transit and impact ridership (Cervero 1998, Cheong and Toh 2010, Givoni and Rietveld 2007).

The last-mile problem is more acute in developing countries, where mass transit systems often remain poorly integrated with other transport modes, compounded by a lack of robust pedestrian and bicycling infrastructure. A survey of trip characteristics for journeys by Delhi Metro found that the first- and last-mile segments together constitute about 40% of the travel time and 48% of the travel cost while comprising only 18% of the total distance traveled (Chidambara & Gupta, 2018). The disproportionate time and cost implications of the first and last mile journeys are an indication of sub-optimal efficiencies, associated with unavailability of reliable connections, longer waiting times and high transfer penalties.

Brons, et al. (2009) showed that high returns can be achieved by facilitating the development of convenient and safe access to transit facilities. For instance, getting more rail transit users to shift away from private vehicles for accessing mass transit stations can yield a number of benefits, including a reduced need for parking lots around transit hubs, reduction in the total number of vehicle miles traveled and a decrease in congestion, air and noise pollution levels (Cervero, 2001).

There is evidence to suggest that new mobility services and intermediate para transit have the potential to be key stakeholders in overcoming the last-mile gap to mass transit. Shaheen and Chan (2016) state that shared mobility services enable commuters to gain short-term access to transit services on an as-needed basis. They highlight the way services such as car-sharing, bike-sharing and micro-transit, due to their on-demand nature, have changed the way urban dwellers access public transportation and make connections to other modes. By integrating with mass transit and offering reliable options of first- and last-mile connectivity, they strengthen the access of mobility as a service, reducing the need for vehicle ownership and promoting greater reliance on shared and public transit modes.

To the concern that Transportation Network Companies (TNCs) are replacing transit trips, it is important to note that TNC usage remains limited even in well-developed markets such as San Francisco, where they represent only 1-2% of all trips (UITP, 2016). A study by Feigan and Murphy (2018) of TNC usage in the United States has found little correlation between peak-hour TNC use and longer-term changes in public transit patronage in different cities, with usage patterns implying the potential of TNCs to serve as last-mile services. Moreover, the study finds that TNC use is associated with decreases in vehicle ownership, a factor that has shown negative correlation to demand for public transport modes (Paulley et al, 2006).

However, there is a lack of sufficient data to understand the potential impacts of on-demand services on public transportation, or their viability in solving the last mile issue. While some experiments have integrated innovative technologies and business models to enhance the service levels of public transit systems, most of these have been small-scale pilot projects that deploy new mobility services as feeders to public and mass transit networks. While municipalities and transit agencies in North America and Europe have started collaborating with the wider ecosystem of mobility service providers, there is insufficient research on the interactions between new mobility enterprises and public transport systems in developing countries with nascent or growing public and mass transit infrastructure.

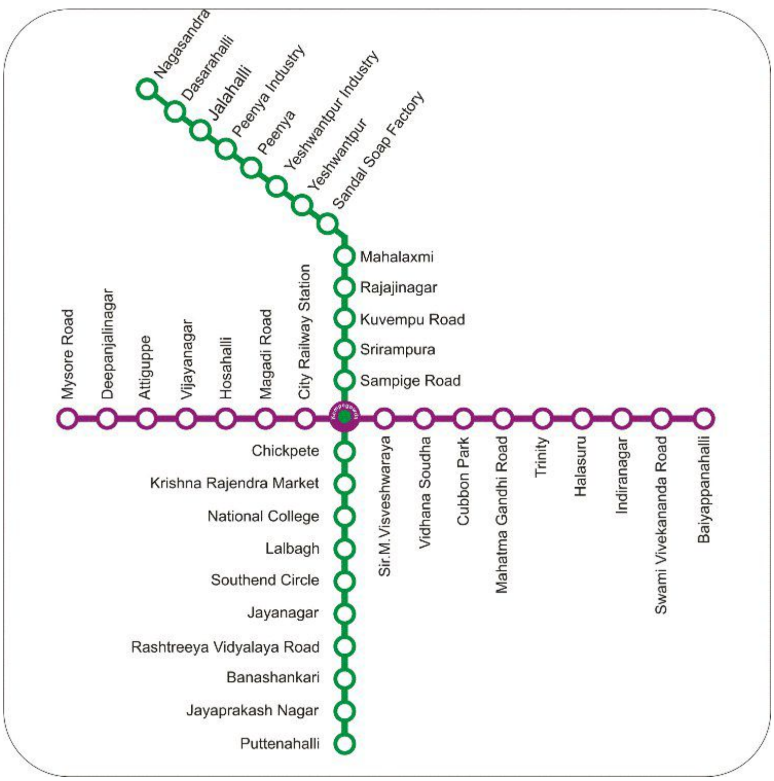

Figure 1. Schematic map of Bangalore Metro Phase 1 (Source: BMRCL)

3. Last-mile connectivity to Bangalore Metro: A case study

Bangalore, with an estimated current population of over 10 million inhabitants, is the third most populous city in India. While the city's population grew by 47.18% between 2001 and 2011 as per Census figures, the number of registered motor vehicles in the city more than doubled in the same amount of time (Praja, 2009; UMTC & DULT, 2011). Currently, the total number of registered motor vehicles in the city stands at 7.3 million (Transport Department, 2018), and a recent study by cab aggregator Ola has found that the city has the slowest vehicular speed in country, at an average of 17.2kmph. There is a critical need for limiting the vehicular traffic growth, and the city's growing mass transit infrastructure offers a viable alternative.

The Bangalore Metro is the mass rapid transit project for Bangalore, with a 42.3km long Phase I network comprising two lines and 40 stations, including one interchange station as seen in Figure 1. The Bangalore Metro Rail Corporation

Limited (BMRCL) is the nodal agency responsible for the construction and operations of the Bangalore Metro. Project construction began in 2007, with the first segment open for commercial operations by 2011. The complete Phase I network was opened to the public in June 2017, leading to a bump in ridership with the number of daily passengers now regularly breaching the 400,000 mark.

Despite recent growth, ridership of the Bangalore Metro remains far below the estimated number of 820,000 daily passengers (DMRCL, 2003). This can be attributed to a number of factors, both internal and external. Internal factors include the lack of metro services at key employment hubs and a limited system capacity due to limited rolling stock. Even as large trip generators are being connected by the Phase 2 metro network, it is expected all metro trains will be upgraded from three coaches to six coaches starting June 2018 (Lalitha, 2018). A key external factor is the lack of integrated and reliable first- and last-mile connectivity to the metro rail system. While BMTC, the city bus agency, continues to struggle with the viability of feeder bus services from several metro stations (Philip, 2018), intermediate paratransit services are not always reliable or conveniently located for accessibility.

The metro currently accounts for about 4.5% of all trips made in Bangalore (Bangalore Development Authority, 2017). By addressing the factors described herein, the modal share of the metro can be augmented. The Station Access and Mobility Program, the initiative that will be analyzed for impact in the following sections, was designed to address the issue of reliable last-mile connectivity to the metro.

3.1. Methodology

The Station Access and Mobility Program (STAMP) was launched with the objective of leveraging the technology-led innovation of new mobility enterprises to bridge the extant gaps in first- and last-mile connectivity to mass transit networks such as the metro rail. Based on inputs from intercept surveys conducted at two metro stations and from discussions with local communities, an innovation challenge was launched inviting solutions for last-mile connectivity to the metro. After a rigorous selection process, two feeder services and one parking service were piloted under STAMP for a period of twelve weeks at a selected metro station in Bangalore. Operations data was collected from the teams for the three pilot projects, and a post-pilot customer survey was conducted with users of the different services. Data was analyzed to understand the impact of the new mobility services on key performance indicators which assess the efficiencies brought about by these services and the pain points solved vis-à-vis the current modes of access to mass transit.

Operations data, collected at three points during the pilot operations- baseline, interim, and final- was used to understand the growth in the services as well as the travel demand characteristics for these services. The objective of the STAMP customer impact survey was to understand the modal shift induced by the services as well as the perceived time savings due to the use of the service. Surveys were conducted after the completion of pilot operations at Baiyappanahalli metro station. Using random sampling, a total of 600 customers were approached both telephonically and at the metro station for the survey (200 for each service). A pre-requisite for the customers to take part in the survey was that they needed to be regular users (at least 3 – 4 times a week) of the metro in combination with the service. A total of 93 respondents, 66 for the feeder services and 27 for the parking service, completed the survey.

3.1.1. Limitations of the study

There are limitations to the scope and findings of the project and its subsequent analysis, which are highlighted below:

- As the pilot operations were deployed in real-time, there was no uniformity in the external conditions faced by each of the enterprises; while Com1 was able to secure physical integration with the station area, Com2 was unable to do so and Com3 faced a closure of its operations for a brief period due to problems faced by the parking vendor. This means that the relative performance of the services cannot be compared but must be analyzed in-situ, in consideration of the context of implementation.

- The three participating enterprises are full-fledged businesses aiming for economic viability, thus the mandate of the project was not to impose any conditions to maintain consistency over the pilot period. As a result, the teams experimented with their business models periodically, leading to changes in the number of transactions that cannot strictly be compared over time.
- The sub-optimal response to the customer survey conducted post-pilot has resulted in very small sample sets for analysis of potential impacts of the services.

3.2. Pilot metro station: Baiyappanahalli

Baiyappanahalli metro station is a terminal station on the east-west purple line of Bangalore Metro. The station is one of the most highly-trafficked in the Phase I network, with BMRCL data revealing that the station receives an average of 60,000 footfalls per day on weekdays. An intercept survey of 1,000 metro users at the station shows that about 73% of metro passengers use buses for last-mile connectivity, followed by 16% that walk to their destinations. Other popular modes of last-mile connectivity include intermediate paratransit such as autorickshaws and taxis (7%) and personal vehicles including motorized two-wheelers and cars (5%).

The station was selected due to its location and its high traffic, to test potential demand for new feeder service options. As a terminal station, Baiyappanahalli is a transitional hub for work trips to key employment centers located in the eastern parts of the city. On weekdays, Baiyappanahalli witnesses an average of over 7,000 footfalls during peak hour, with 3,000 outgoing and 4,300 incoming commuters. This equates to 50 metro passengers leaving the station every minute, seeking last-mile connectivity to their final destinations. This was considered an appropriate scale of passenger flows for testing the limited-size pilot operations.

3.3. The pilot projects

In this section, we offer a brief description of the three enterprises that conducted pilot operations at Baiyappanahalli metro station. For the purposes of maintaining anonymity, the enterprises will be referred to as Com1, Com2 and Com3 through the paper.

Com1: Com1 offers motorized two-wheeler (scooter and motorbikes) rentals for short distance, intra-city trips, with pickup and drop off at multiple touchpoints across the city. The value proposition of the service is that it provides access to on-demand, end-to-end mobility without the hassle of vehicle ownership. The service aims to solve the pain points of waiting time and ease of access to mass transit by making available pickup and drop-off points at station areas and around high-traffic origin and destination points. Charges for the Com1 service are distance and time based, with trips being charged at INR 5/km and INR0.5/min. The Com1 pilot started with three pickup and drop-off points, of which one was at the metro station, and a fleet of forty vehicles, based on a demand assessment carried out by the service provider.

Com2: Com2 is an intra-city carpooling platform which matches empty seats in private vehicles with extant travel demand in the same direction. The platform's value proposition is two-fold: it offers ride-givers an opportunity to share the cost of fuel by utilizing the unused inventory of empty seats, and it offers ride-takers high levels of comfort and end-to-end travel at affordable cost, without the hassle of vehicle ownership. The service aims to solve the pain points of waiting time and low in-vehicle comfort with assured seating and additional amenities such as air-conditioning. For ride-takers, charges of the Com2 service are distance-based and set by the ride giver, ranging from INR 0-5/km, with an average of INR 3.5/km for four-wheelers. The Com2 pilot was launched with a heavy marketing campaign at the metro station to acquire ride-givers and ride-takers, as well as promotional programs at trip generation points such as corporate tech parks.

Com3: Com3 is a parking aggregator that provides information on availability and prices of parking in a given area and allows vehicle owners to reserve available parking spaces. The service provider also works with parking vendors for the optimization and management of their services. Com3's value proposition is two-fold; for parking vendors, the service improves profitability by attracting users to under-utilized inventory and by increasing the transparency of operations. For vehicle owners, the service provides information on parking availability and provides assured booking of safe and secure parking. The service aims to solve the pain points of time and fuel spent in searching for parking, as well as the risk of damage to the vehicle in unsecured parking areas. For metro station areas, users are charged at the prescribed rates as laid down by the metro, and thus do not have to pay extra for the Com3 services. The Com3 pilot started with the integration of the parking management software at the main parking lot servicing the metro station. For the purposes of the pilot operations, Com3 enabled only the back-end of its services to support parking and transaction management for the vendors. The features of parking aggregation and online booking of services were not fully enabled during the pilot period.

4. Results and analysis

Salient numbers from the operations data for the three pilot services, collected over period of twelve weeks, are given Table 2. Beyond the comparable numbers, each business model provided different operations data, which will be briefly analyzed here to understand trends and potential impact of the services.

The total number of transactions is the number of transactions recorded by each enterprise during the pilot period, and varies based on the size of the pilot, which can be equated to the size of the inventory. Com1 had an average fleet size of 62 vehicles over the course of the pilot- the enterprise started with 40 vehicles and expanded to 77 by the end of the pilot period. For Com2, the average size of inventory is calculated on the basis of the number of offered rides, which varies day-on-day. The average trip lengths for the feeder services are 9kms and 12kms, for Com1 and Com2 respectively. These are longer than average trip lengths for feeder services- this may be explained by the pilot station being a terminal station, and key trip generation points being outside the typical catchment area of the network.

Table 2. Operations data for the pilot projects

	Com1	Com2	Com3
Total no. of transactions	2874	1365	13415
Transactions per day	51	24	216
Average trip length	9.33	11.9	-
Average size of inventory	62	45	1000

* The number of days of pilot operations is considered to be 56 for Com1 and Com2, and 62 days for Com3 (see Section 4.1.1. for explanation).

For Com3, the available inventory size remained fixed at 1000 parking spots. The Com3 service had to halt operations for three weeks of the pilot period due to problems with the parking vendor.

4.1. Service usage patterns

Operational data provided by the teams has been analyzed to understand transaction patterns, the travel demand and operational efficiencies of the pilot projects.

4.1.1. Transaction flows

Figure 2 shows the typical weekly transaction patterns for the three services. The Com1 and Com2 services showed distinct weekly variations in use, with an insignificant number of transactions being registered at the metro station on weekends. Considering that both services are designed for work commutes, this finding is expected. Excluding holidays and weekends, the two services are thus assumed to have been in operation for 56 days over the pilot period.

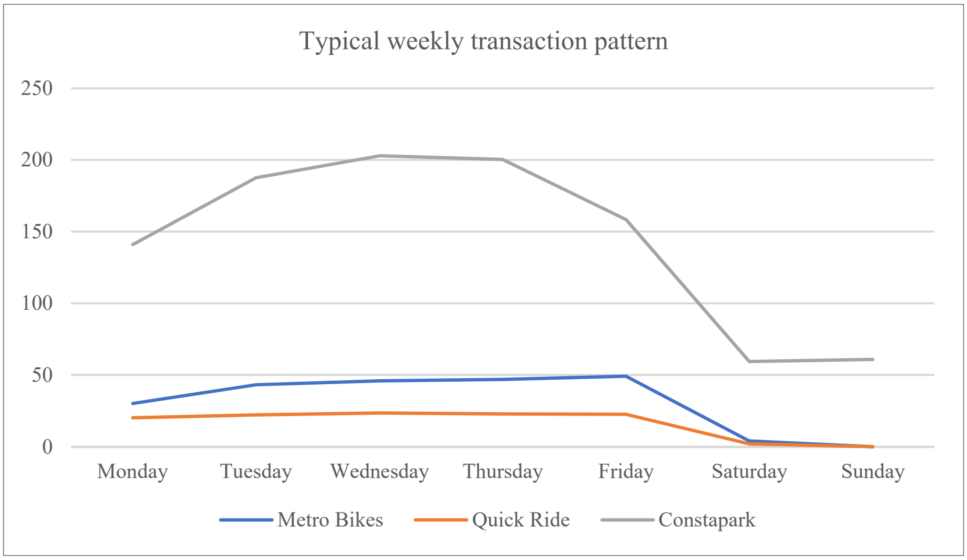

Figure 2. Typical weekly pattern of transactions

In contrast, Com3 services were in use through the week, albeit with distinctly less volumes over the weekend; however, the service was also non-operational for three weeks of the pilot period. As a result, the service is considered to have 62 operational days over the pilot period. Through interviews with parking vendors and users, it was determined that the weekend usage was for leisure trips made to parks and other recreational activities along the metro line.

Transaction flows also exhibited a pattern over the course of the day, as shown in Figure 3. For Com1 and Com2, the majority of transactions took place during the morning and evening peaks. The morning peak lasted from 7 to 11 in the morning for Com2 and from 8 to 12 for Com1. The evening peak coincides for both services, lasting from 4 to 8 in the evening. 56% of Com's daily transactions took place during the morning peak, and 29% during the evening peak. For Com2, 33% transactions took place during the morning peak and 52% during the evening peak.

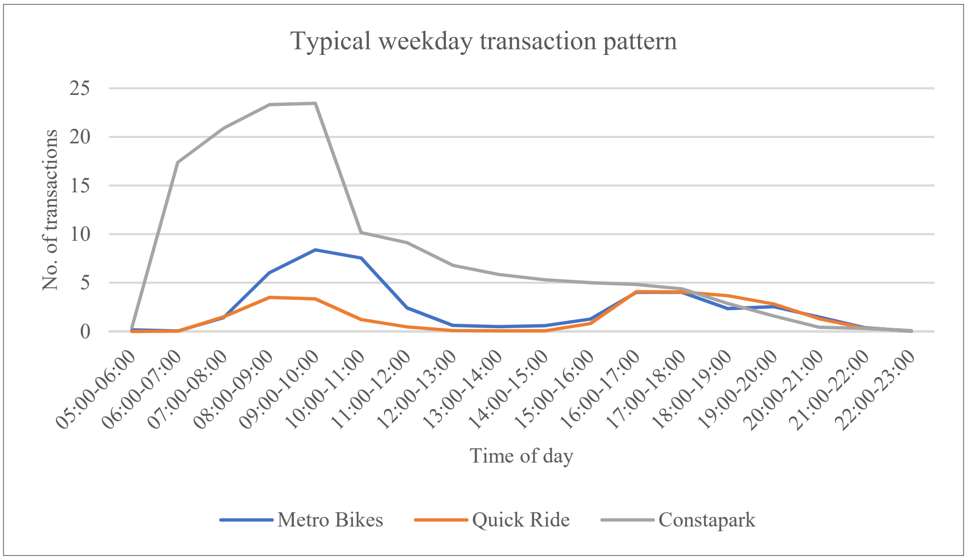

Figure 3. Typical weekday pattern of transactions

4.1.2. Direction of travel demand

An analysis of the usage pattern of the feeder services shows that they act as extensions to the metro rail network, providing connectivity to destinations that are beyond the catchment area of the existing network.

A randomly chosen subset of the users' origin-destination pairs were geo-coded and mapped to understand the usage of the feeder services and the direction of travel demand (see Figure 4). A clear pattern emerges, with both Com1 and Com2 services being used primarily to access employment centers at a distance of 10-12 kilometers from the terminal station. The map on the left shows the usage of the Com1 service from the terminal Baiyappanahalli station, with the thickness of lines demonstrating the frequency of trip occurrence for a given destination. While a few diffused lines show trips occurring to other parts of the city, the majority of trips have destinations in the Whitefield region to the east of the city, which is home to tech parks and corporate campuses.

The map on the right shows the trips taken by the Com2 service that originate at the pen-ultimate and terminal metro stations. Here, three clear destination regions are defined, each of which correspond to a concentration of corporate campuses or tech parks. On-road distances to Manyata Tech Park and the Outer Ring Road cluster of campuses are higher than to Whitefield, corroborating to the fact that average trip distance over the pilot period is higher for the Com2 carpool service.

From the demonstrated usage pattern, we can infer that there is a sizeable market for frequent micro-transit feeder services between metro stations and major employment centers. This inference is supported by discussions with corporate transport managers and corporate employee transport providers, who are actively looking to integrate the metro rail network to facilitate employee transport, for savings in commuting time and in the cost to company of providing transportation for employees.

In addition to reorienting their employee transport management strategies to integrate the metro rail, corporate companies and tech parks are actively incorporating new mobility services as part of a larger suite of transport solutions. From hosting marketing campaigns promoting carpooling among employees to providing parking space for pickup and drop-off points for the Com1 scooter rentals, corporate stakeholders are integral to enabling a modal shift away from private vehicles towards public and shared mobility.

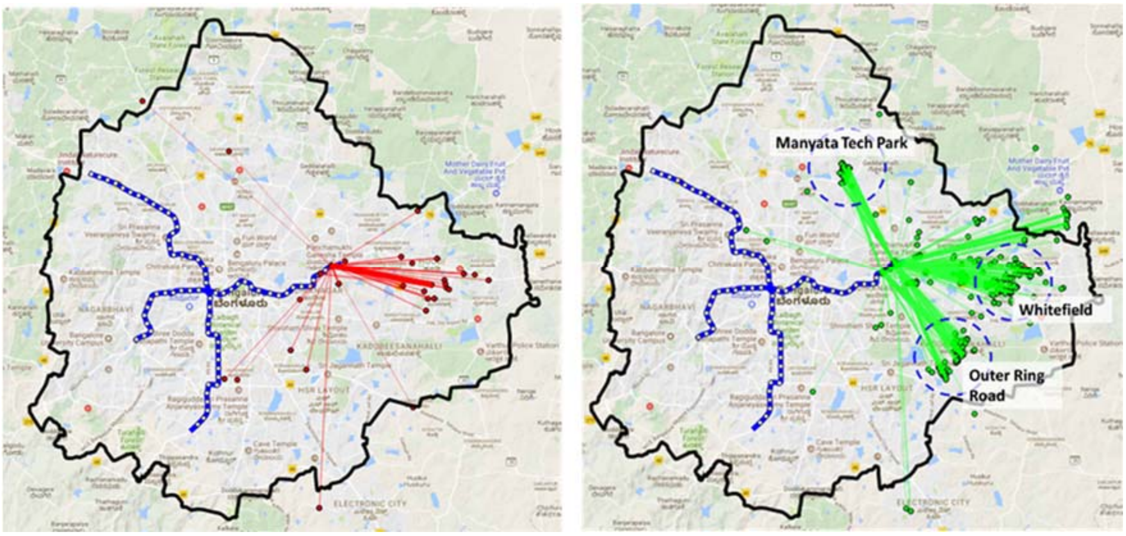

Figure 4. Origin-destination mapping of trips via (left) Com1 service; (right) Com2 service

4.1.3. Achieving operational efficiencies

Here, we briefly analyze the trends in growth achieved by the three enterprises, both in terms of absolute growth in number of transactions as well as the efficiency of operations for the feeder services.

Table 3. Weekly transaction numbers for pilot operations

No. of transactions	Com1	Com2	Com3
Week 1	16	65	2323
Week 2	141	102	1409
Week 3	184	102	2656
Week 4	115	118	1461
Week 5	202	122	802
Week 6	261	120	652
Week 7	165	118	-
Week 8	281	120	-
Week 9	307	131	-
Week 10	399	108	862
Week 11	235	44	1149
Week 12	305	119	889
Week 13	263	123	923

Table 3 shows the weekly transaction numbers for the three pilot projects. Not considering the first week of operations at which point the service had not launched fully, Com1 showed an average week on week growth of 13%

over the pilot period. They did this while augmenting their fleet and the number of pick-up and drop off points. Com2 too, demonstrated healthy growth over the pilot period, with a week-on-week average growth of 15%. Com3 however, showed a negative average growth rate of -1% week-on-week (not counting the three weeks for which it wasn't operational), primarily due to reduced usage of the software by the vendor before the service use was halted.

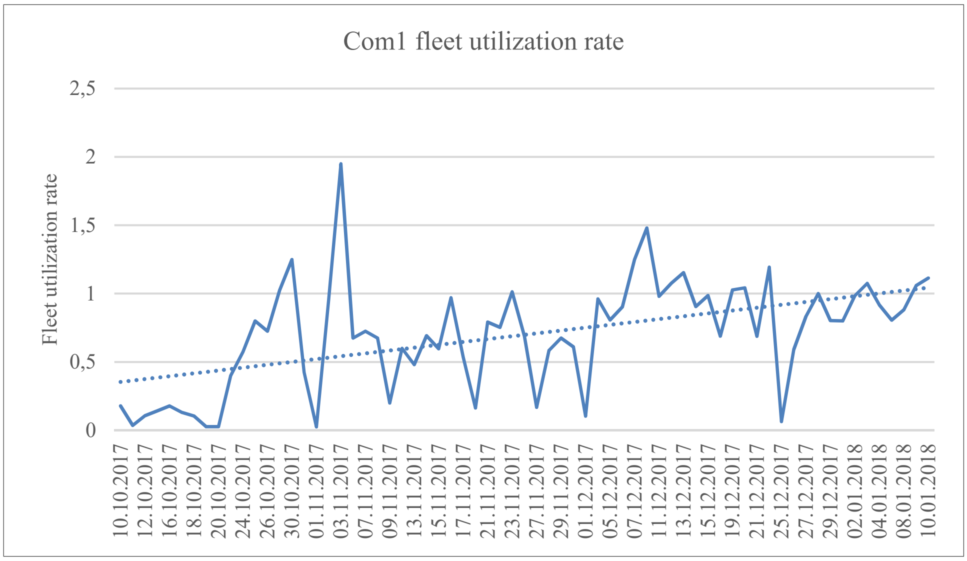

Figure 5. Change in fleet utilization rate of Com1

When looking at operational efficiency, the Com1 business model depends on higher levels of fleet utilization for the unit economics to work. Figure 5 shows the fleet utilization rate for Com1 through the pilot period. The fleet utilization rate showed consistent growth, with the average daily fleet utilization in the final month of the pilot found to be 83% greater than that of the first month.

For Com2, the operational efficiency lies in converting a greater number of ride requests and ride offers to completed rides. Figure 6 shows the pattern in the number of requested, offered and completed rides over the pilot period. It is seen that the number of rides requested (demand) and the number of rides offered (supply) has steadily risen, with demand showing overall growth of 15% while supply has grown 22%. While the number of completed transactions has grown 8% by the end of the pilot, the conversion rate has remained steady at about 50%. This means that 50% of all ride requests were converted to completed trips. The lack of improvement in conversion rate is not surprising, considering that changes in conversion rates require scale for increased probability of matches between the offered and requested rides.

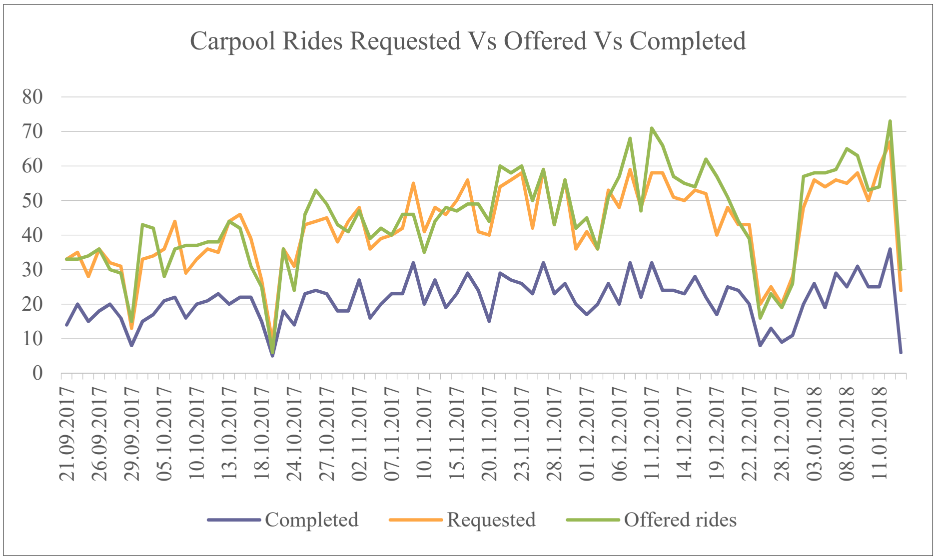

Figure 6. Change in conversion rate of Com2

4.2. Service impacts

While the STAMP services were of a limited scale and the available sample set of responses quite small, some initial findings of the service impacts were analyzed.

4.2.1. Perceived time savings

Results from the customer survey indicate that there is a high perceived time savings from the use of new mobility services. Com1 users reported a perceived time savings of 22 minutes per trip, while Com2 users reported a perceived time savings of 19.5 minutes per trip. Considering that about 85% of Com1 and Com2 trips took place during the morning or evening peak, this is a significant time savings for service users. Com3 users reported a more modest time savings of 10 minutes per trip.

Both the Com1 and the Com2 services cut down on the perceived waiting time, while Com1 goes one step further to cut down the transfer penalty as well, providing additional perceived time savings. Com1 allows customers to pre-book a scooter at a selected pickup and drop-off point nearest to the station, thereby assuring the availability of the vehicle and reducing the wait time to zero. Further, by having a pickup point that is physically integrated with the metro station, Com1 further reduces any potential transfer penalty by allowing people to move seamlessly from the metro to the last-mile feeder service.

Feng et al (2015) have shown that the availability of real-time information can cut down on perceived waiting time. Com2 provides an estimated time of arrival of the carpool vehicle, while also offering the option of tracking the vehicle on a map. In comparison to Com1, Com2 lacks a pickup and drop-off point at the metro station, due to which it is expected that the perceived time savings is slightly diminished despite the additional comfort of in-vehicle time.

Both the new mobility services cut down on in-vehicle time when compared to public feeder buses, due to higher average speeds and more direct routes. According to the Bangalore Mobility Indicators 2011 (UMTC & DULT, 2011), the average speed of private vehicles was 25 kmph while that of public transport was 15kmph. While average traffic speeds have come down considerably in the city since, it is expected that public transport continues to be a slower mode of travel. The perceived time savings of these services are thus distinctly higher than public transport.

4.2.2. Modal shift induced

The customer survey asked users their previous modes of first or last mile connectivity that were replaced by the new mobility services. From the limited sample of responses, the Com1 and Com2 feeder services are found to have induced a modal shift of 43% from personal vehicles for the first-/ last-mile segments and a shift of 48% from public transport. The remaining modal shift is explained by replacing the following modes: walking (5%), intermediate para transit (3%) and rail (2%).

While the modal shift from public transport was high, the near-equal shift from private vehicles to shared mobility is encouraging. Research has shown that drive-alone access trips to transit stations, regardless of distance, emit levels of pollutants that are not too much below those of the typical commute due to high levels of tailpipe emissions during starts and stops (Cervero, 2001). Thus, the impact of shared mobility services on inducing a modal shift away from private vehicles for first- and last-mile connectivity is significant.

For vehicle owners using the parking lot managed by Com3 software, the customer survey asked them about their previous mode of transport before using the metro. 70% had shifted from public transport, while 22% had shifted from private vehicles. Of the 70% that shifted from public transport, 79% stated that they would use public or shared mobility to access the metro if the parking facility was not available.

Taken in conjunction, the two findings suggest a push and pull approach to limiting private vehicle use for accessing metro stations, by ensuring the availability of demand-responsive mobility services while restricting the supply of parking. Going further, parking could be prioritized for carpooling vehicles and commuters with mobility limitations. At the same time, real-time information on parking availability would enable vehicle-owners to make the decision of leaving their vehicle at home if parking is not available.

4.3. Ecosystem building

The STAMP initiative was able to successfully engage with government and non-government stakeholders to prioritize last-mile connectivity and integration for seamless public transport. Notable, ecosystem-level outcomes of the program are enlisted below.

- STAMP engaged with mass transit authorities from 5 cities across the country, for facilitating robust last-mile connectivity solutions to their transit systems.
- Following the engagement with the metro rail agency, the program worked with the city bus agency, the Bangalore Metropolitan Transport Corporation (BMTC), to facilitate last-mile connectivity to major bus terminals.
- STAMP worked with corporate tech parks and companies, and connected over 30 corporate companies to the metro through the STAMP services.
- STAMP promoted collaboration between new mobility enterprises for cross-platform integration, setting the stage for the development of new, integrated business models.
- Most notably, STAMP enabled Com1 to demonstrate a significant value-addition as a last-mile service, leading to a contract with the BMRCL for last-mile services at 36 of the 40 metro stations in the city.

At the same time, there is much more to do towards building a more supportive ecosystem for innovative mobility solutions to thrive while contributing to more sustainable and equitable urban mobility. For instance, the regulatory framework in Bangalore prevents the development of bus aggregator and other micro-transit solutions that could be leveraged for improving the service levels of public transport (Philip, 2017).

5. Discussion and Conclusion

The STAMP pilot implementation was a first attempt to create a platform for collaboration between public and private mobility service providers, to improve public transportation in the city. Performance of the different services was mixed- while Com1 and Com2 both demonstrated a modest growth rate over the pilot period, the Com3 parking solution faced challenges from external circumstances due to which pilot operations suffered a break at the six-week mark.

The Com1 solution showed greater growth in terms of the size of pilot operations, going from a fleet size of 40 to 77 vehicles and increasing the number of pickup and drop off points from 3 to 28. The carpooling solution did register a demonstrable growth; however, the lack of physical integration of the solution in the form of a dedicated pickup and drop-off point was felt to be a keen disadvantage in increasing the total and supply and demand on the platform. The solution may also benefit from supporting incentives such as reserved carpool parking. The Com3 solution was also found to be dependent on external factors, with the need expressed for a strong metro parking policy that enforced digital transactions for greater transparency.

In terms of time saved, the services showed promising results, with perceived time savings equivalent to a total of 470 working days. This finding shows the potential of new mobility services to induce a shift to mass transit, when deployed at scale. A first- and last-mile modal shift was already demonstrated over the pilot period, with almost equivalent numbers of users having shifted from public transport and personal vehicles. Considering the poor economic viability of feeder services along certain routes in Bangalore, this finding can be used to further experiment with contracting new mobility enterprises with demand-adaptive business models for providing first- and last-mile connectivity.

In addition to the direct impact of the services, there has been a noticeable impact of the STAMP initiative at the city level. Transit agencies have taken greater note of the need for last-mile connectivity and established an openness to working with new mobility enterprises and technology companies to solve the issue. With the expanded operations of Com1 services at 36 metro stations, there is greater opportunity to understand the potential impacts of new mobility enterprises on mass transit ridership and sustainable urban transport systems.

The pilot operations took the first steps towards integration between modes, with physical integration of the Com1 two-wheeler rental service at the station area. Going forward, there is a need to leverage advances in digital technology to provide deeper multimodal integration, with information, fare and service integration between the range of available mobility services and public transportation. Enabling this will require strong political will and a willingness to demonstrate results on-ground. Pilot projects can provide the necessary testing grounds to document and deliver proof of potential impact and must be executed in greater numbers to provide data for decision-making.

Further research is needed to build upon the findings of the STAMP study. The STAMP model is currently being replicated in one more Indian city, which is expected to expand upon the current research and provide points of inter-city comparison for future directions of work.

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