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Gadepalli, Ravi; Gumireddy, Sushmitha; Bhamidipati, Srirama; Cats, Oded

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Impact of introducing a metro line on urban bus services

Ravi Gadepalli [a,*], Sushmitha Gumireddy [b], Srirama Bhamidipati [c], Oded Cats [d]

[a] Transit Intelligence LLP, Bengaluru 560 041, India
[b] Transit Intelligence LLP, Hyderabad 500 016, India
[c] Independent Consultant, The Hague, The Netherlands
[d] Department of Transport & Planning, Delft University of Technology, The Netherlands

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ABSTRACT

Many cities have introduced metro rail systems over the past two decades, particularly in developing countries. However, there is lack of knowledge on the impacts of new lines on the service and ridership for the related urban bus lines, and in particular those directly affected by the opening of the new service(s). We undertake a comprehensive analysis of service supply and travel demand patterns of the newly introduced metro rail and the existing urban bus services for the city of Bengaluru, India. We analyse network configuration, service schedule and passenger demand ticketing data to establish the relative travel characteristics of the two modes and the impact of the metro on bus service supply and demand. Additionally, the travel characteristics before and after the first wave of Coronavirus pandemic were analysed to establish its impact on the users of both the modes. Demand for bus services has proven to be more resilient than for metro services while other travel characteristics of users remained similar before and after the pandemic. The travel demand, bus network and service supply characteristics were used to identify a framework for bus service rationalisation for improved integration with the metro. The two systems were observed to be inherently complimentary due to users' preference of buses for shorter trips and metro for the longer trips, even on bus routes operating parallel to the metro. Hence attempts for network rationalisation need to identify routes with high share of bus demand parallel to the metro before selecting them for rationalisation.

1. Introduction

Metro rail-based mass transit systems have witnessed a rapid growth over the past two decades. Globally, 73 out of the 178 metro systems active in 2017 started their operations after beginning of this millennium. Developing regions are leading this growth with 38 out of the 43 new metro rail systems inaugurated between 2010 and 2019 located in China, India, Middle East and North Africa (UITP 2018). Just in India, where there are 13 cities with an operational metro network of about 700 km as of spring 2021, metro systems are set to expand to 1,985 km across 23 cities in the next five to seven years, while many more systems are being planned to be introduced in the coming years (Swarajya 2021).

The introduction of new metro services has significant consequences for the co-existing large, dense and often over-crowded urban bus networks. The introduction of new mass rapid transit services is often accompanied by the re-design of urban bus services, especially those in proximity to the new high-capacity corridors. For example, in the case of a new metro line in Amsterdam, the Netherlands, the opening of the new line was accompanied with a significant re-design of the bus and tram networks so as to avoid duplications and offer feeding services to the new north–south corridor (Brands et al. 2020). Similarly, the bus service network in the Haifa Bay area, Israel, has been subject to a major overhaul with the opening of the new Bus Rapid Transit system so as to offer an integration system (Ishaq and Cats 2020). Changes included removing or rerouting overlapping routes, launching new feeder services, increasing the frequencies of existing feeder services, extensing of routes to transform them into feeders. Several studies have examined the passengers demand and travel times impacts of new mass transit services using smart card data, including the cases of metro services in Amsterdam (Brands et al. 2020) and Nanjing, China (Fu and Gu 2018), and light rail lines in Los Angeles (Lee et al. 2017) and Minneapolis, USA (Cao and Schoner 2014). These studies have investigated the ridership attracted to the new mass transit line(s), overall changes in public transport ridership and travel time savings experienced by public transport users. (Fearnley et al. 2018) offer a review and a *meta*-analysis of empirical findings for cross-elasticities between public transport modes. They

* Corresponding author.
E-mail addresses: ravi@transitintelligence.in (R. Gadepalli), sushmitha@transitintelligence.in (S. Gumireddy), o.cats@tudelft.nl (O. Cats).

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concluded that the evidence for cross-elasticities across modes is scarce with the exception of bus and rail relations and with respect to changes in fares, travel time and headway. However, the relevance of duplications between different modes has not been addressed. In these stream of studies on the supply and demand impacts of mass transit services, there is lack of knowledge on the impacts of new mass transit lines on the service and ridership for the related urban bus lines, and in particular those directly affected by the opening of the new service(s).

Ultimately, the opening of new metro lines should allow for the integration of bus and metro services so as to maximize the level of service delivered to passengers. Unfortunately, this is seldom the case in the Indian context. Errampalli et al. (2020) point out the lack of coordination between different public agencies responsible for planning and operating different public transport modes and services due to institutional, legal and financial barriers. The city of Bengaluru (also known as Bangalore) presents a representative case for other cities in developing countries building metro rail systems. Bengaluru has a population of more than 12 million inhabitants spread across the municipal area of 741 sq.km. and the urban agglomeration around it. The city currently has about 48.7 km of operational metro rail network spread across 2 corridors out of which the phase-1 network of 42.3 km started operations in June 2017. The system is owned and operated by the Bengaluru Metro Rail Corporation Limited (BMRCL). Another 127 km of metro network is under construction and is scheduled to be operational over the next five years. Bengaluru is also home to India's largest urban public bus fleet of 6,690 buses, planned and operated by the state-owned Bengaluru Metropolitan Transport Corporation (BMTC). These buses are operated across 2,203 routes.

The onset of the Coronavirus pandemic (Covid-19) since early 2020 has added an extra dimension to public transport planning. On one hand, Covid-19 has resulted in reduced travel demand due to users' perceived risk of contracting the virus on crowded public transport systems. On the other hand, the rapid downturn in economic growth and employment opportunities has reduced the disposable income available for travel, thereby increasing the reliance on affordable public transport services. Therefore, it is important to understand the impacts of the pandemic on travel behaviour while planning for public transport systems in the near future (Gkiotsalitis and Cats 2020).

In this study, we consider the case of Bengaluru, India and analyses the public transport services provided by bus and metro rail systems to establish the impacts of the city's new metro system on urban bus services. We analyse both the demand and supply characteristics of the two systems to establish their current level of complementarity and efficiency in utilising available resources. We have also established the impact of Covid-19 pandemic on public transport demand by comparing bus and metro travel characteristics prior to the outbreak of the pandemic with those post the first wave of the pandemic but before the onset of the second wave.

In the following section we describe our approach for analysing both supply and demand aspects of the bus and metro services. Next, we detail the corresponding data analytics and results. We conclude with a discussion of our key findings and how they can be used as inputs to an integrated network planning and frequency setting exercise to rationalise the bus network for improved integration with the metro.

2. Case study description

The city of Bengaluru (also known as Bangalore) is a representative case for other cities in developing countries building metro rail systems. Bengaluru has a population of more than 12 million inhabitants spread across the Municipal area of 741 sq.km. and the urban agglomeration around it. The city currently has about 48.69 km of operational metro rail network spread across 2 corridors out of which network of 42.3 km, commonly called as the phase-1 network, started operations in June 2017. The system is owned and operated by the Bengaluru Metro Rail Corporation Limited (BMRCL). Another 127 km of metro network is under construction and is scheduled to be operational by 2025. Bengaluru is also home to India's largest urban public bus fleet of 6,690 buses, including 859 Air-Conditioned (AC) and 5,831 Non-AC buses planned and operated by the state-owned Bengaluru Metropolitan Transport Corporation (BMTC). These buses are operated across 2,203 routes out of which 101 routes operate AC buses.

Bengaluru's public transport has a mode share of 41% of all vehicular trips in 2019 within which about 90% of the trips were made using BMTC, with a daily ridership of approx. 3.5 million, while the metro with a daily ridership of about 0.45 million catered to the rest (CMP Bengaluru (2020)). Public transport ridership has reduced drastically since the onset of Coronavirus pandemic, due to an overall decline in travel activity in the city and a shift in travel behaviour due to increased preference to work and study from home. Even before the pandemic, the bus ridership in the city has witnessed a significant and steady decline since 2015–16 when the daily ridership stood at 5 million passengers per day. This decline is due to a combination of factors including the introduction of the new metro rail system along corridors with high demand bus routes, rapid growth of personally owned cars and two-wheelers growing by of more than 30% and commercial taxi services including ride-hailing and ride-pooling services growing by more than 60%, while the BMTC bus fleet only grew by 2%. This paper focuses on the bus-metro relationship to isolate the impact of metro introduction on bus ridership, within the overall set of issues that have led to the current drop in bus ridership.

3. Methodology and data

The impact of the Phase-1 metro on urban bus services is analyzed from the service supply and travel demand perspectives. In our empirical investigation, we deploy a series of statistical analysis. Origin-destination matrices are constructed from ticketing data to then be analysed in terms of their before-after changes in travel pattern distributions. The demand analytics is then complemented with a GIS analysis of supply changes for the corresponding periods and the calculation of key performance indicators of service outputs. The supply analysis is used to classify routes into several categories based on their relation to the newly introduced metro service. Fig. 1 presents a summary of the steps followed to undertake this analysis while the detailed methodology is explained below.

The data sources employed are summarised below:

Relative travel characteristics of bus and metro users: We have compared the travel characteristics of bus and metro users after the phase-1 operations have stabilized, i.e., in January 2020. In addition, we also examine demand in March 2021 to understand the impact of Covid-19. This analysis helps understand the clientele for the two modes better and therefore plan for their integration accordingly.

BMTC's service supply changes in the metro influence area: BMTC has monthly performance evaluation and service updation practices based on Key Performance Indicators (KPIs) like vehicle utilization (km/bus/day), revenue generated, ridership, punctuality etc. Hence, we analyzed the service supply and financial performance KPIs of urban bus services before and after the implementation of phase-1 metro to understand the supply adjustments made in response. We have analyzed BMTC KPIs for three time points: January 2017 (i.e., before phase-1 metro), January 2020 (after phase-1 metro but before Covid-19) and March 2021 (after the first wave of Covid-19 but before the onset of the second wave).

We acknowledge that there might have been other factors influencing demand and supply of bus services during the selected period, apart from the introduction of the metro. However, there have been no other systematic differences in the city impacting the urban development and user behaviour patterns to a similar extent. Even if there are such changes, we assume that they apply uniformly between the metro influence area and the rest of the city and are therefore factored into the analysis.

Overview of Analysis	Data sources	Outputs

Travel demand characteristics of metro and bus users
• Comparison of overall bus and metro travel demand characteristics
  • Daily and Hourly variation in demand
  • Trip length characteristics of users
  • Impact of Covid-19 on demand of both modes
• Travel demand characteristics on BMTC routes competing with the metro (>=2 km overlap)
  • Trip length distribution of users on competing routes classified into:
    • % trips < 2 km along the metro
    • % trips >= 2 km and <5 km along the metro
    • % trips >= 5 km along the metro
	• Metro ticketing data
	  • Hourly Origin-Destination matrix
	• Bus ticketing data
	  • Trip wise tickets including Origin, Destination, Fare and Route no.
		• Inputs for bus and metro integration
		  • Identification of bus routes to be rationalised
		  • Matching peak hours of supply with metro
		• Inputs for overall bus service improvements
		  • Improved evening peak service

Service supply of metro and bus systems
• Network analysis
  • Bus and metro network mapping in GIS
  • Create metro influence areas: 400m and 2 km along the streets
  • Select bus routes & stops in metro influence area
  • Measure % route length (% stops) overlapping with metro
• Service analysis
  • Bus routes in metro influence area
  • Supply before and after metro (Jan 2017 Vs Jan 2020)
  • Supply before and after Covid (Jan 2020 Vs March 2021)
  • Hourly service volumes planned and delivered
• Rationalising routes with high overlap with metro
  • Identify length of overlap
	• Metro services
	  • Stops and corridors in GIS
	  • Service schedules
	• Bus services
	  • Stop Latitudes and Longitude
	  • Route database with stops
	  • Route-wise service schedules
	  • Route wise KPIs
		• Identification of parallel route (>=25% stops within 400m of metro) and feeder routes (<25% stops within 400m)
		• Segregate parallel routes to competing routes (>=2 km overlap) and non-competing routes (< 2 km overlap)
		• Identify % of trips which are 2 km or longer on competing routes

Fig. 1. Overview of the analysis performed, data sources enabling it and outputs obtained.

3.1. Approach for travel demand analysis

The relative travel characteristics of the metro and bus systems are analysed using their ticketing data. The metro passenger demand data is a combination of smart cards used by regular users and tokens used by occasional users. This data includes the tap-in and tap-out stations and times of each ticket, thereby allowing to construct the Origin-Destination (OD) details of all passenger trips. The BMTC ticketing data was collected using the back up of data from Electronic Ticketing machine (ETM), i.e., handheld devices used to issue tickets on board buses. This includes route-wise origin, destination, time of ticket issue and fare for all trips. However, ETM devices do not capture the concessional bus pass users like student and employee pass users who constitute about 50% of the total demand in buses. Despite this limitation, ETM's still capture about 1.7 million users' tickets daily, pre-Covid, thereby providing a large sample to understand the overall travel patterns of bus users. The data includes origin, destination, time and fare of all tickets issued. Data on transfer of trips between bus routes and between bus and metro rail systems is not available which results in different legs of the journey counted as separate trips. As a result, it is likely that the percentage of short trips may be slightly overestimated. However, this would only be a small percentage of the overall trips given the predominantly radial nature of the BMTC network which would allow for limited number of transfers between routes.

The ticketing data from the metro and buses is analyzed using Excel- and Python-based data-analytics tools to investigate the following for January 2020 and March 2021.

1. **Daily and Hourly variation of travel demand** on metro and bus systems to check if the peak and off-peak demand patterns for both modes are similar
2. **Trip length distribution** of bus and metro users, as it is one of the key attributes determining individual's choice between different modes. Buses typically have better network coverage and are easily accessible while the metro has limited network coverage and the stations are either elevated or underground, making access to metro longer. Hence, bus trips tend to be more competitive for shorter trip lengths. However, metro's faster in-vehicle speed results in shorter journey times if trip lengths are longer than 10 km. We investigate whether this holds for Bengaluru based on trip length distribution data.
3. **Impact of Covid-19** on overall public transport demand

3.2. Approach for service supply analysis

Various secondary data sources are used for the demand and supply analysis of bus and metro systems. The bus and metro networks are plotted in Geographic Information Systems (GIS) using secondary data on stop and route locations provided by the respective operating agencies. We analyse the service supply impacts of metro on BMTC using its route network and service frequency characteristics within the metro influence area.

Network mapping and analysis: We map the phase-1 metro and bus networks in GIS to allow for geospatial analysis of the two systems. Metro network mapping is carried out manually using the data on metro stop locations along the two corridors. Bus network mapping is a more complicated task. The bus stop and route data available in Comma Separated Value (CSV) format as a part of the Intelligent Transport System (ITS) database of BMTC is exported to GIS format. However, the lack of the exact path information between stops of various routes required manual compilation of the alignment of each route. All the 2,203 routes operated by BMTC until January 2020 are plotted using this method. While some of these routes have fewer/ no services in the post- Covid analysis period, the route alignments remained the same.

The overall service influence area of the metro depends on various local factors such as the built environment, public transport network layout, quality of infrastructure and services, weather and other local cultural factors (Soest et al., 2019). Therefore, based on data from metro user survey data (CSTEP (2018)) along with local stakeholder consultations we assumed metro to have a radius of 2 km from each of its stops, i.e., each stop acts as the point of entry/ exist to the metro system and is assumed to serve users within 2 km of its vicinity. We used the Bengaluru road network maps from open street maps (OSM) to identify the 2 km service area around each metro station. Given our focus on bus and metro integration, we also identify bus stops within 400 m walking distance of metro, assuming a walking speed of 5 km per hour and 5 min as the threshold walking time people have for transfer between bus and metro. The bus routes operating in the 400 m and 2 km influence area of the metro are identified from GIS by selecting the bus stops in these areas and selecting the routes linked to these stops. All the bus stops in the metro influence areas are considered as candidate stops for a possible transfer to the metro. The bus routes overlapping with the metro were identified by selecting the routes with two or more stops within the 400 m influence area of metro stations. The length of overlap with the metro is derived by measuring the distance between the farthest of the stops in the 400 m influence of the metro.

All the bus routes with bus stops within the 2 km influence of the metro are classified according to the extent of overlap and the percentage of the route overlapping with the metro. Due to gaps in BMTC data regarding the exact alignment for some routes, stops are considered as proxy for length, e.g., if 10% of stops are in the influence area, 10% of the route length is also assumed to be within the influence area. Accordingly, routes are segregated into two broad categories:

1. **Feeder routes to the metro**: Routes with<25% of their stops within 400 m of metro are assumed to be feeder routes as their length along the metro corridor is limited and therefore are likely to be used as feeder services to and from metro.
2. **Routes parallel to the metro**: Routes having more than 25% of their stops within 400 m influence of the metro. These parallel routes are the likely candidates for rationalization based on their travel demand analysis

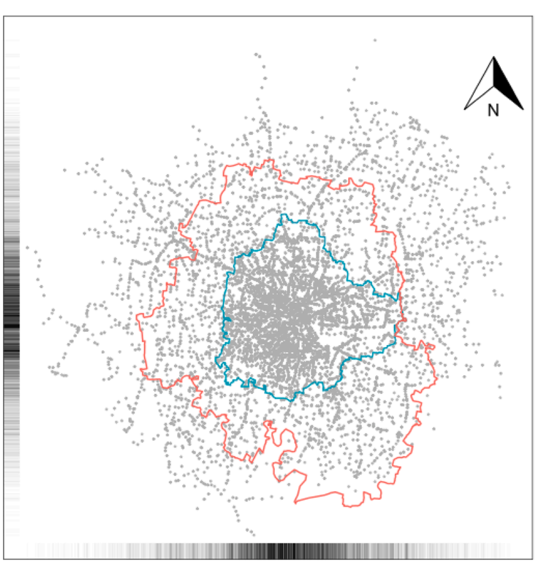
Service analysis: The analysis focuses on three key indicators of bus service delivery within the 2 km metro influence area: number of routes, number of scheduled services (daily buses) operating on these routes and the effective-km of service they provide, i.e., the vehicle-km of service accessible to users.

We present the results of the analysis in the following order: Network mapping and identification of bus routes in metro influence area, bus and metro travel demand analysis, bus service supply analysis and scope for rationalisation.

4. Data analysis and results

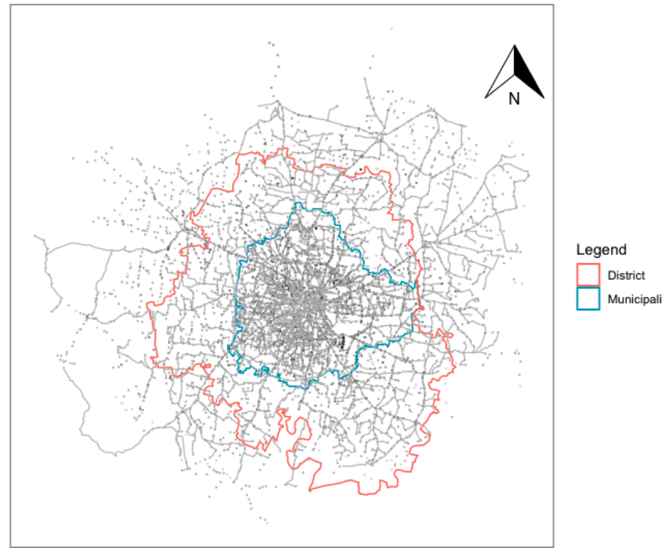
4.1. Bus and metro network analysis

Fig. 2 presents the spatial distribution of bus stops, routes, and their combination across Bengaluru. It can be observed that the stop density decreases progressively from within the municipal boundaries towards the Bengaluru urban district boundaries and the outer metropolitan area beyond the district boundaries. Fig. 3 presents the location of metro stops, represented according to their corridor, i.e., Green and Purple, overlayed on the bus stop network. We also show the 400 m and 2 km influence area from the metro stops used to identify the bus stops and routes that lie within these areas.



A

Fig. 2A. Bus stop network of Bengaluru.



B

Fig. 2B. Bus route network of Bengaluru.

4.2. Bus and metro travel demand analysis

The comparative travel demand patterns of metro and bus systems, before and after the coronavirus pandemic, were analysed in Python using the data sources listed in section 2.2. The analysis covered 2,967,260 metro trips and 21,293,999 bus trips made between 19 and 25 January 2020 and 846,488 metro trips and 8,366,255 bus trips made between 1 and 7 March 2021.

Public transport demand before and after Covid-19 first wave: Total overall travel demand for metro dropped from an average weekday ridership of 0.45 million per day in Jan 2020 to 0.13 millions per day in March 2021, i.e., 29% of the pre-pandemic demand-just before the second wave of the pandemic started. While part of the demand variance can be explained by the effect of seasonal variation in travel demand, majority of it can be attributed to the significant disruption to travel patterns caused due to the Covid-19 pandemic, such as, increased preference for home-based work and education, restricted hours of commercial activity and reduced discretionary trips such as shopping and recreation. Table 1 summarises the overall metro and bus demand patterns before and after Covid-19. In the case of buses, the average daily ridership dropped from 3.04 million per day to 1.22 million per day for the corresponding period, indicating a drop to 40% of pre-pandemic ridership during weekdays and 39% overall. Hence, demand for bus services has proven to be more resilient than for metro services. This could be because metro use is dominated by middle and higher income users who have shifted to home-based work and education by means of telecommunication. The continued usage of buses is presumably attributed to lower income groups who depend on buses due to affordability reasons (CMP Bengaluru (2020)). These include labour in public health, construction and manufacturing sectors and many other informal jobs across sectors which required travel to work even during the pandemic. The daily variation in demand indicates a relatively constant demand across the week with marginal increase on Mondays and a marginal drop during the weekends both before and after the pandemic.

Hourly distribution of demand: The hourly variation of bus and metro travel demand before and after Covid-19 is summarised in Fig. 4. Both metro and bus have a distinct morning and evening peaks in demand. The morning and evening peaks for the metro occur between 9 and 11 AM and 6–8 PM respectively, while the corresponding peaks for buses are 8–10 AM and 5–7 PM, respectively. Together the six hours covering 8–11 AM and 5–08 PM cover 52–58% of daily metro demand

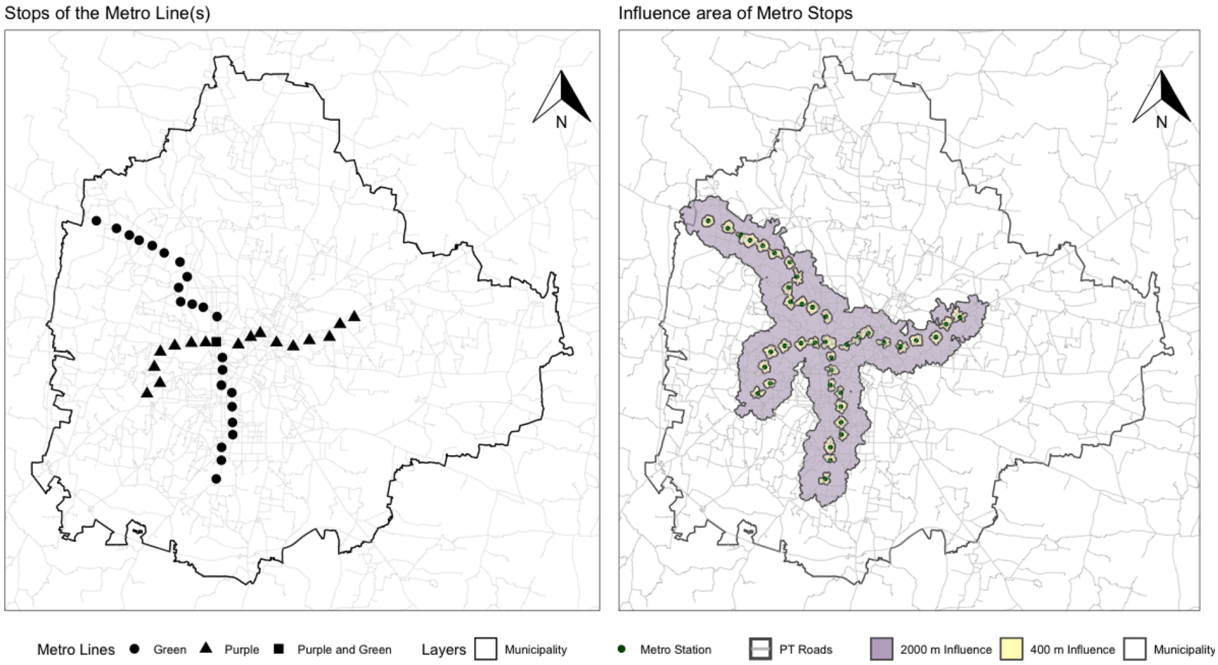


Fig. 3. Metro network of Bengaluru and its 400 m and 2 km influence area.

Table 1
Daily variation of metro and bus demand (Jan'20 and Mar'21).

Attribute	Metro Ridership (millions)	Share of weekly metro ridership	Bus Ridership (millions)	Share of weekly bus ridership	Metro Ridership (millions)	Share of weekly metro ridership	Bus Ridership (millions)	Share of weekly bus ridership	Metro ridership as a % of pre-pandemic	Bus ridership as a % of pre-pandemic
Month	Jan-20	Jan-20	Jan-20	Jan-20	Mar-21	Mar-21	Mar-21	Mar-21		
Monday	0.47	16%	3.31	16%	0.13	15%	1.34	16%	28%	41%
Tuesday	0.44	15%	2.98	14%	0.13	15%	1.20	14%	29%	40%
Wednesday	0.44	15%	2.98	14%	0.13	15%	1.21	14%	29%	41%
Thursday	0.44	15%	2.96	14%	0.13	15%	1.20	14%	29%	40%
Friday	0.46	15%	2.98	14%	0.13	16%	1.18	14%	29%	40%
Saturday	0.40	13%	3.11	15%	0.13	15%	1.17	14%	33%	38%
Sunday	0.32	11%	2.98	14%	0.07	8%	1.07	13%	22%	36%
Total	2.97	100%	21.29	100%	0.85	100%	8.37	100%	29%	39%

and 47–51% of bus demand, indicating the significance of peak demand. The peak share of trips increased post-Covid indicating a likely decline in discretionary trips made during off-peak hours.

The sharp decline in bus demand after the end of the evening peak (i.e. 7 PM), in contrast to the metro peak extending up to 8 PM, is primarily due to scheduling gaps in the urban bus service. The trip wise service schedule analysis of BMTC for both Jan'20 and Mar'21 established that that the service supply drops after 6 PM by design, due to the current crew scheduling practices at BMTC, that end many crew shifts by 6 PM. At the same time, metro provides a close to constant level of service throughout the day. The urban bus services thus have the potential to serve the peak demand better by extending its evening peak services until later in the evening to attract additional ridership. To address this, we identify the specific schedules terminating early in the evening and analyzed them further.

We observed that in March 2021, 1,236 out of 5,438 scheduled i.e., 23% of the services, terminated by 6 PM. 99% of such schedules are of buses with crew operating on 'General Shift' which is a 11 h shift that currently starts between 6 and 8 AM and ends between 6 and 7 PM. BMTC can instead stagger their start times to ensure later start and end timings to extend its peak services until 8 PM to match the evening peak of the metro. We estimate the potential revenue benefit of such rescheduling based on the hourly revenue made by the bus services currently available in the evening peak. The depot-wise revenue increase can potentially add up to approx. INR 11 lakh (USD 15,000) per day, i.e., about INR 48 Cr (USD 6.4 m) annually at no additional cost, highlighting the significant benefits of addressing the evening peak problem. This can address up to 10% of the annual gap in farebox recovery of BMTC based on pre-Covid ridership and at the same time offer bus services to address metro users' first and last mile needs.

Trip length patterns of metro and bus users: Trip length is another key travel demand indicator in determining users' mode choice. The demand between all Origin-Destination (OD) pairs of tickets was combined with the distance between all stations to analyze the trip length distribution of metro users. We derived trip lengths of bus users according to the fare collected and using BMTC's fare charts. While the ticketing data also had ticket origin and destination data, we observed significant errors in the data as the stops were observed to not match with the expected fare, possibly due to incorrect data entry by the bus conductors. Given that the fares paid are already verified by users buying the ticket, we expect this to be as a more reliable source of data.

The average trip length of metro users remains relatively constant at about 9.5–9.6 km across the week and even before and after the pandemic, as shown in Table 2. The average trip length of bus users across Bengaluru was 10.9 km in January 20 and reduced to 9.5 km in March 21. While buses have higher average trip lengths, the distribution

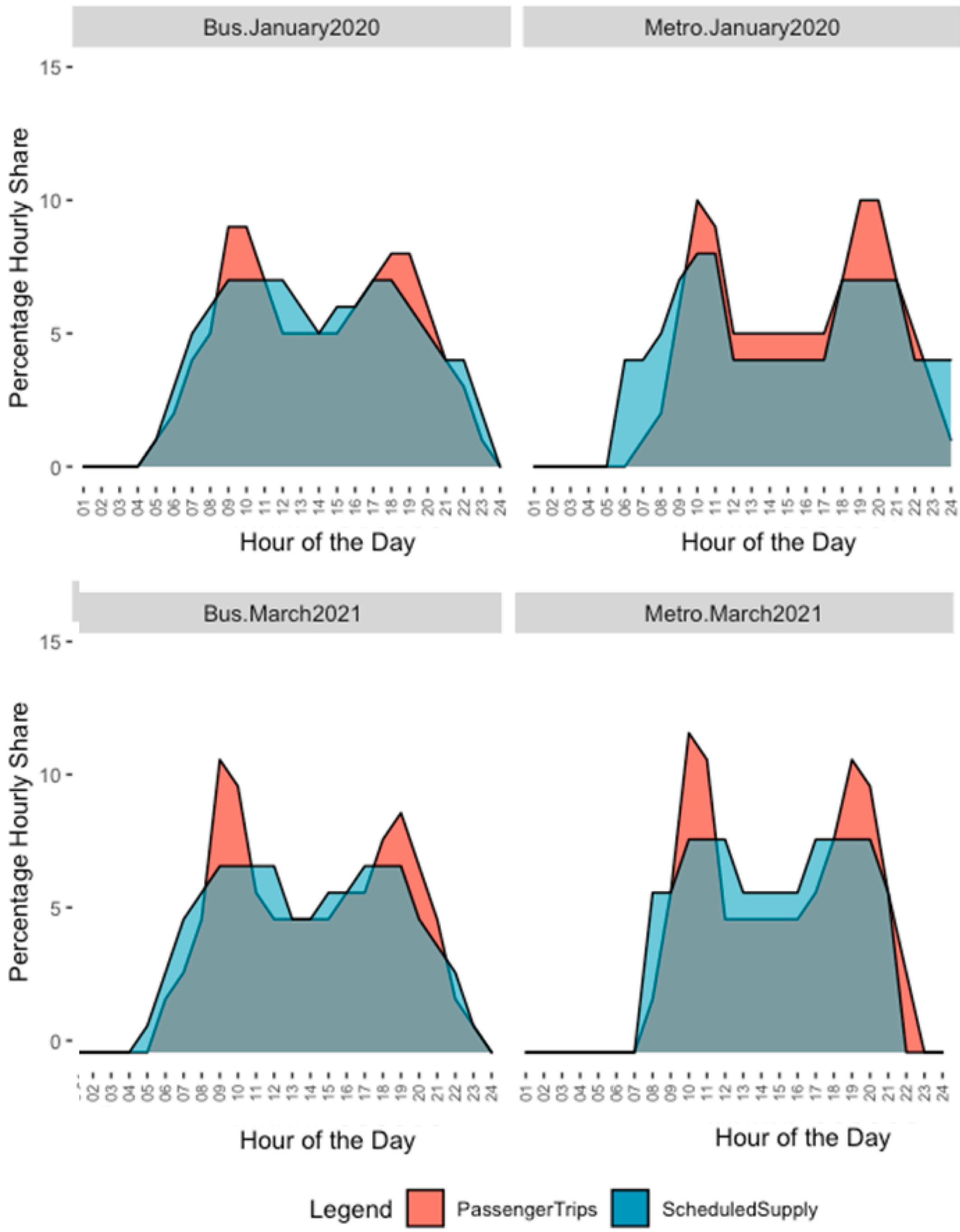


Fig. 4. Hourly public transport demand and supply (January 2020 and March 2021).

of trips shows that buses have a high share of trips longer than 15 km, made on their suburban routes, which is skewing their average. In fact, majority of the bus trips are shorter than 5 km (42% in January 20 and 52% in March 21) and 63–64% of all bus trips are shorter than 10 km. The majority of metro demand are 5–15 km long with 61–64% of the trips, while another 16–17% of the trips are longer than 15 km.

Bus trip lengths in the metro influence area are shorter compared to the rest of the city at 5.7–6.2 km. This indicates that in areas which offer a choice between metro and bus services, users prefer metro for longer trips and buses for shorter trips, possibly due to the trade-off between short access times to the buses and faster travel time for the main-haul journey on the metro. Note that this change occurred even though the bus service network has not been adjusted in response to the introduction of the metro lines. Hence, as the metro connectivity will increase in the future, buses are likely to cater more to the shorter trips while metro takes over the longer trips, even in the absence of integrated network planning. Consequently, BMTC will need to focus more on shorter route-length high frequency services in metro influence area to attract more short distance commuters. This would be a significant departure from the current network layout, wherein about 50% of the routes are longer than 25 km, providing suburban and across the city connectivity. However, we also note that the shorter bus trip lengths could be influenced by the land-use development characteristics specific to the metro influence area which may be encouraging such travel pattern. Therefore, a more careful analysis of the factors influencing bus trip lengths needs to be conducted before adopting a paradigm shift in bus network planning practices.

Table 2
Trip length distribution of bus and metro users (Jan'20 and Mar'21).

Mode	Metro	BMTC Overall	Metro Influence area	Metro	BMTC Overall	Metro Influence area
Month	Jan-20	Jan-20	Jan-20	Mar-21	Mar-21	Mar-21
<2 km	4%	17%	33%	4%	21%	38%
>=2 & <5 km	16%	25%	33%	18%	31%	28%
>=5 & <10 km	37%	22%	21%	34%	13%	9%
>=10 & <15 km	27%	15%	8%	27%	24%	22%
>=15 km	16%	22%	5%	17%	12%	3%
Total	100%	100%	100%	100%	100%	100%
Average trip length (in km)	9.5	10.9	5.7	9.6	9.5	6.2

4.3. Key findings from bus and metro travel demand analysis

In summary, the demand analysis showed that the public transport travel characteristics of users have not changed significantly before and after Covid-19. However, the overall travel demand reduced possibly due to an overall dip in economic activity, travel restrictions and change in travel preferences to home based work and education.

The travel demand pattern analysis of bus and metro users shows an inherent complementarity between the two modes. Users choose buses for shorter trips (typically shorter than 5 km) and metro for the longer trips (trip lengths longer than 5 km). The daily and hourly variation of demand across both the modes are overall similar, except for the drop in bus demand at the end of the evening peak due to an abrupt reduction in service supply. These insights provide valuable inputs to multimodal network planning of the two systems.

4.4. Service supply analysis

Urban bus services in metro influence area: Table 3 presents the summary of BMTC service evolution overall and within the metro influence area. The route network remained relatively static between January 2017 and January 2020, both in terms of the overall number of routes and the share of routes in the metro influence area. The total operational bus fleet of BMTC increased by 12% over these years, while the fleet allocated to routes in the metro influence area have also increased by 11%. Despite the increase in fleet, the effective-km (revenue earning service km) by BMTC at the city level increased by only 6% while effective-km in the metro influence area increased by just 2%. The growth rate of effective-km has not matched the growth in number of buses primarily due to the increasing congestion across the city. This is even higher in the urban core of the city where the metro operates, therefore resulting in declining vehicle utilization (km/bus/day) of buses. For the bus routes passing through the metro influence area, about 32–33% of their total effective-km are within the influence area. The total revenue per-km has increased by 15% overall and by 13% within the metro influence area. This indicates a marginally lower bus demand within the metro influence area, presumably due to the presence of metro as -a high quality alternative to the bus.

Table 3
Summary of 2017 and 2020 bus service supply.

Attribute	Jan 2017	Jan 2020	% Change w.r.t Jan 2017
Total number of routes	2,201	2,203	0.1%
Routes within 2 km of metro	2,013	2,013	
% routes within 2 km of metro	91%	91%	
Total operational fleet	5,569	6,254	12%
Operational fleet within 2 km of metro	5,163	5,714	11%
% fleet within 2 km of metro	93%	91%	−1.4%
Total monthly effective-km	33,065,286	35,126,995	6%
Monthly effective-km within 2 km of metro	11,027,311	11,214,540	2%
% Eff-km within 2 km of metro	33%	32%	
Total revenue per km (in INR)	32.9	37.9	15%
Revenue per km of routes within metro influence (in INR)	33.4	37.7	13%

Bus and metro service overlap: BMTC operates both urban and suburban routes, with 40% of the routes shorter than 20 km acting as urban routes, 33% of the routes longer than 30 km acting as suburban routes and the remaining 27% of the routes in the 20–30 km category providing long distance connectivity within the city. A total of 1,903 out of 2,203 routes are observed to have some level of overlap with the metro. out of which 1,474 routes have an overlap of 2 km or more. Even though the overlap is longer than 2 km, its proportion within the total route is<25% of the total route length for 1,062 of these routes. Most of these routes are longer suburban routes providing connectivity to the city centre. Hence curtailing the portion of these routes overlapping with the metro to reduce duplicity in service can necessitate multiple transfers for these users to access the city centre. In contrast, routes overlapping for 25% or more of their total length are mostly the ones operating in the city centre where the metro is also operational. Table 3 shows that upto 66% of bus trips within metro influence area are shorter than 5 km and hence their passengers are unlikely to shift to the metro in the absence of their current route. They may instead shift away from public transport altogether. Therefore, even in this case, curtailing routes to reduce network duplicity with the metro can have a detrimental effect on the overall public transport demand.

Overlapping routes need to be evaluated from the demand perspective to check if rationalizing these routes will lead to improved metro ridership or rather lead to a shift to private forms of mobility. Ticketing data is analysed further for the overlapping routes to identify trips for which both origin and destination lie within 400 m of metro stations, meaning that the trips are parallel to the metro. The trip lengths of such trips are classified into short overlap (<2 km) and long overlap (>= 2 km) trips, under the assumption that the longer overlap trips are likely to shift from bus to metro. The percentage share of such long overlap trips out of the total demand on the route was used to shortlist the routes with high share of trips which are likely to shift to the metro.

Table 4 presents the summary analysis of network and demand overlap of bus services with the metro. The analysis shows that 1,903 out of 2,203 BMTC urban bus routes have some overlap with the metro. However, only 734 out of these routes have some passenger trips with both origin and destination within 400 m access distance to the metro. Within these, 27 routes have at least 25% of their users travelling for more than 2 km parallel to the metro and 132 routes have at least 10% demand travelling 2 km or more parallel to the metro. These lines constitute the priority candidates for rationalisation because their users are likely to shift to the metro post the rationalisation. Together these

Table 4
Summary of bus routes overlapping with the metro.

Indicator	Number of Routes
Total urban bus routes	2203
Route with stops within 400 m of metro	1903
Routes with more than 2 km of overlap with the metro	1474
Routes with trips having more than 2 km overlap	735
Percentage (%) demand overlapping for more than 2 km	
>=25%	27
>= 10 and < 25 %	105
>= 5 and < 10 %	166
<5%	297
No trips along metro even though route has greater than 2 km overlap	140

routes constitute only 6% of BMTC routes and demand indicating that the number of buses competing with metro for ridership is relatively low. Therefore, even though BMTC has many overlapping routes in terms of supply alignment, the demand on these routes is unlikely to shift to the metro if these routes are removed as the travel patterns on these routes do not match with the connectivity provided by the metro.

5. Conclusions and recommendations

This study presents a detailed review of the impact of introducing a metro rail service in the city of Bengaluru, India on its existing urban bus service. We have carried out a comparative analysis of bus and metro and within bus comparison before and after the metro has been introduced to establish this impact. Additionally, the impact of the Covid-19 pandemic on travel demand patterns for both the modes is also investigated. A combination of datasets like route networks, schedules and ticketing data were used to perform this analysis.

The network analysis of the urban bus services identify specific routes in city centre overlapping with the metro. Instead, these resources can be better reallocated to routes in the rapidly extending and under-supplied parts of the urban agglomeration. Moreover, the travel demand pattern analysis of bus and metro users based on their ticketing data showed an inherent complementarity in user choice between the two modes with buses being preferred for trips shorter than 5 km and metro for the trips longer than 5 km, wherever the services are available. The trip length category of 5–10 km is where both modes have relatively similar ridership levels. Overall, the demand for both modes fell sharply due to Covid-19, with metro demand dropping to 29% and bus demand dropping to 39% of the pre-pandemic demand. However, within the demand attracted, the travel patterns like peak hours and trip length patterns did not change before and after the pandemic. This indicates that as the pandemic eases out in the future, the in-vehicle travel characteristics are likely to be remain similar to pre-pandemic user behaviour, only the absolute demand level being uncertain. We also identify that suboptimal crew scheduling practices need to be improved to provide more bus services in the evening peak hours.

The urban bus service network has remained unchanged overall following the opening of the metro services. 91% of all urban bus services continued to operate within the 2 km influence area of the metro even after three years of the metro's existence. 1,903 out of 2,203 BMTC routes, amounting to 86% of all routes, have some overlap with the metro, with 1,062 routes having an overlap of 2 or more km. Only 132 routes, representing 6% of the overall BMTC services have 10% or more of their passenger trips parallel to the metro, thereby implying that even though the bus operator has routes parallel to the metro, it does not carry a significant travel demand which is both generated and attracted parallel to the metro. Hence, we conclude that users of majority the overlapping routes are unlikely to shift to the metro if these routes are removed as their travel patterns do not match with the connectivity offered by the metro. They may instead shift away from public transport altogether.

The findings from our demand and supply analysis can be used as inputs to an integrated network planning and frequency setting exercise that will rationalise the bus network for improved integration with the metro. A deeper analysis of the bus network configuration would also help identify opportunities to improve the bus network's internal efficiency in addition to its integration with the metro. Furthermore, it can be used to better respond to user demand across the city and between different hours of the day as well as more efficiently and effectively allocate bus service resources throughout the operational area. Future studies may investigate cross-modal elasticities for bus and metro service attributes as well as the phasing of bus network re-design in the context of a rapidly evolving metro network. Similarly, the disaggregated travel behaviour analysis of bus users before and after metro introduction, which was not possible in this study due to data limitations, can provide useful insights for bus network redesign.

CRediT authorship contribution statement

Ravi Gadepalli: Conceptualization, Methodology, Supervision, Resources, Writing – original draft. **Sushmitha Gumireddy:** Formal analysis, Software, Data curation, Visualization. **Srirama Bhamidipati:** Formal analysis, Software, Resources, Data curation, Visualization. **Oded Cats:** Conceptualization, Methodology, Writing – review & editing.

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