Unpublished Technical Article

Ridership Estimation and Evaluation of the Proposed Inner Ring Metro Corridor in Bengaluru City

By

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Background

Based on the inputs received from Transportation Engineering (TE) lab, Indian Institute of Science (IISc), the Director, IISc had proposed and presented the idea of a fully underground inner ring metro (IRM) rail corridor (with a proposed metro station at IISc as well) to Chief Secretary of Karnataka during a meeting held on March 23, 2019. This matter was subsequently forwarded by Chief Secretary office to Bangalore Metro Rail Corporation Limited (BMRCL) for their kind consideration. In due course, MD, BMRCL had requested the TE lab at IISc to carry out demand assessment and evaluation of the proposed IRM corridor and help BMRCL take an appropriate and informed decision on implementation of IRM corridor, based on a due scientific analysis.

Introduction

This article aims at providing scientific evidence supporting the proposed metro corridor along Inner Ring Road (Inner Ring Metro) in Bengaluru city from the point of view of sustainable transportation planning. Bengaluru metro line has been approved to be constructed in four phases as follows:

- Phase 1 - 42.3 km (working condition)
- Phase 2 - 73.95 km (under construction)
- Phase 2A - 19.46 km (approved)
- Phase 2B - 38 km (approved)

The existing metro lines (purple & green lines) have 40 metro stations with Kempegowda station as interchange and the entire stretch is opened for public since 2017. Metro phase 2 with two new lines (pink and yellow lines) and extension of purple and green line have 58 stations and 4 interchanges. Purple line extension towards Challeghatta and green line extension towards Anajanapura township is expected to be opened for utilization by 2020 or 2021. Further, the remaining sections of phase 2 is anticipated to be opened for public use by 2024. Blue lines connecting Silk board - KR puram and KR puram - Kempegowda International Airport are approved for construction in two phases; where, phase 2A has 13 metro stations and phase 2B has 17 metro stations respectively. Additionally, BMRCL has proposed to construct an Inner Ring Metro (IRM) line for about 34 km by 2031 and has been detailed in the recently released Comprehensive Mobility Plan, 2019. IRM constitutes of 23 new metro stations and 6 interchanges considering the completion of all other phases of metro project. IRM is suggested as it connects all the major commercial and educational hubs which might help in reducing the traffic congestion at city level. In this article, IRM is referred to as brown line. Thus, it is expected that Bengaluru will have 207 km of metro network with 148 metro stations and 13 interchanges spreading across the city. The main objective of this article is to estimate the ridership of proposed IRM. Map showing all the metro lines is presented in figure 1.

Figure 1. Metro Phase 1, 2, 2A, 2B and Inner Ring Metro

The article explains the estimation of ridership for the proposed Inner Ring Metro using mode choice model which is the third stage of four-stage travel demand modelling. Model is developed for the year 2020 with metro phase 1 and forecasted for the year 2030 with metro phase 2, 2A, 2B and IRM. The analysis will give an insight about the metro ridership for the proposed corridor along with other four phases of metro corridor. The study highlights the importance of metro corridor in terms of increase in modal shift to public transport. The comprehensive analysis of different scenarios is explained in the following sections.

Model Development

The technical details obtained from BMRCL is digitised and used for further analysis. Bangalore Metropolitan Area (BMR) of 8,005 sq. km is considered for the evaluation. Trip end equation as developed in the report '*Sustainable Transport Measures for Liveable Bengaluru by Verma et. al. Indian Institute of Science, Bangalore*' is utilized for modelling. Trip productions and attractions are forecasted for private and public transport using the trip end equations given in table 1.

Table 1. Trip End Equations for Private and Public Transport

Mode	**P-A**	**Trip End Equations**	R^2
Private	Production	0.56 x POP* + 1344.34	0.46
	Attraction	0.76 x EMP* + 6877.28	0.40
Public	Production	0.42 x POP + 4080	0.43
	Attraction	0.76 x EMP + 6231	0.40

**POP - Population, *EMP – Employment*

(Source: Sustainable Transport Measures for Liveable Bengaluru by Verma et. al., 2018)

Trip end equations are utilized to project the base year population to 2020 and 2030. Travel demand for the years 2020 and 2030 is forecasted using the base year model.

The two scenarios considered for the study are as follows:

- **Business as Usual Scenario (BAU)** - Scenario where metro phase 1, 2, 2A and 2B (purple, green, pink, yellow, blue and brown lines) are considered for the modelling.
- **Inner Ring Metro Scenario (IRM)** - Scenario where Inner Ring Metro is assumed to be open for public use along with other metro phases.

In addition, it is assumed that all the lines have 6 coach trains and the capacity is assumed as 69,000 (Sixty-nine thousand) passengers per hour per direction (pphpd). The paper titled '*Suitability of alternative systems for urban mass transport for Indian cities by Verma, IISc Bangalore and Dhingra, IIT Bombay'* is referred for the assumption towards metro capacity.

The impact in the mode share due to increase in metro network is described in the subsequent sections.

Mode Choice Model

Modal split is the third stage in Travel Demand Modelling process where mode wise trip matrix for each mode are obtained from the overall trip matrix developed from trip distribution stage of Travel Demand Model. Multinomial Logit Model (MNL) which demonstrates the proportion of people choosing a particular mode for travel is used for mode choice analysis. Table 2 gives the detail of estimated parameters.

Table 2. Estimated Parameters

Variables	Value	Variables	Value
Car	0 (fixed)	Age (Auto)	-0.294
TW	3.94	Gender (Auto)	-0.0171
Auto	0.307	Income (Auto)	-0.143
Cycle	6.99	Age (Cycle)	-0.261
Walk	7.55	Gender (Cycle)	-0.0169
Bus	2.81	Income (Cycle)	-0.0119
Metro	1.46	Age (Walk)	-0.292
Travel Time (Generic)	-0.0678	Gender (Walk)	-0.0159
Travel Cost (Generic)	-0.0079	Income (Walk)	-0.0486
Walking time (PT)	-0.156	Age (Bus)	-0.218
Waiting time (PT)	-0.0171	Gender (Bus)	-0.0163
Interchange time (PT)	-0.0678	Income (Bus)	-0.0134
Age (TW)	-0.788	Age (Metro)	-0.258
Gender (TW)	-0.049	Gender (Metro)	-0.0113
Income (TW)	-0.0491	Income (Metro)	-0.0214
Null log-likelihood: -5701.859 Final log-likelihood: -2084.096 Rho-square: 0.634			

**PT - Public Transit*

In this model car is fixed as the base mode and the parameter values for the rest other modes are estimated. The negative sign signifies that with respect to car, if the travel time of other modes increases then the utility of that particular mode will be reduced. For example, if the travel times increases then the utility of choosing a mode reduces over car. Similarly, if the household income of a TW owner increases by a unit, then the utility of choosing TW reduces over car by -0.049. It can be summarized from this table that as the travel time, travel cost, income etc increases, people tend to choose car over other modes (since car is fixed as base mode).

Scenario Evaluation

Modal Share

Mode share of each mode estimated using the parameters mentioned in Table 2 is presented in figure 2. Modal share of metro has increased from 6.4% in 2020 to 10.2% in 2030 (BAU). It is because, in 2020, metro network of only 42km length is in operating condition; whereas, in 2030 - BAU scenario, metro network will be well established by about 169km length considering the completion of metro phase 2, 2A and 2B projects. Further, it is observed that with the addition of Inner Ring Metro line of 34km, metro modal share accounts for about 16.2% when compared to BAU scenario. There is nearly 59% increase in the metro mode share with the addition of IRM line in 2030. On the contrary, the share of private modes (car and two-wheeler) have decreased by 22% in 2030 IRM scenario when compared to 2030 BAU scenario. Also, there is about 9% increase in NMT users in IRM scenario. Thus, increase in the metro network has resulted in increased metro users and NMT users. Overall, the share of sustainable transport modes (bus, metro, cycle and walk) is increasing from 61.8% in 2030 - BAU scenario to 67.4% in 2030 - IRM scenario. Hence, as per push and pull concept, increasing the network coverage of metro encourages private vehicle users to shift to public transport modes.

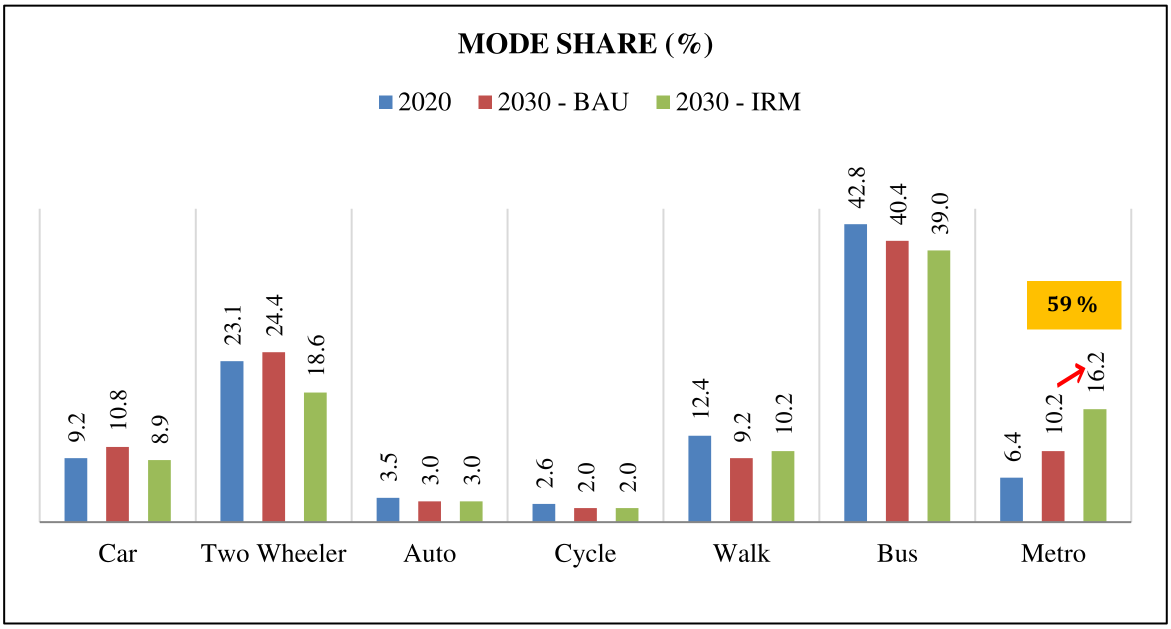


Figure 2. Comparison of the Modal Share for the years 2020 and 2030

Metro Ridership

The change in the metro ridership for different scenarios evaluated in this study is presented in figure 3. Metro ridership has increase from 3.9 lakhs in 2020 to 8.5 lakhs in 2030 - BAU scenario. The 120% increase in the metro ridership is primarily due to two reasons. One reason is due to increase in the metro network coverage to 169 km that covers the heavily congested locations like the ring road where the IT companies are situated. The other reason is reduction in the headway time which reduces the waiting time for the commuters. From table 2, it is seen that, as travel time of a particular mode increases the utility of choosing that mode decreases. Therefore, reducing the travel time increases metro ridership. The proposed metro phases 1, 2, 2A and 2B however does not have proper connectivity in the central areas of the city. The smaller number of interchanges result in increased walking time to metro stations which makes metro less attractive compared to other modes. The IRM line is proposed on the busy corridor of the city which are usually congested providing more coverage for the central part of the city. Every location where the IRM line crosses other metro phase lines has an interchange which helps the commuters to have a seamless journey.

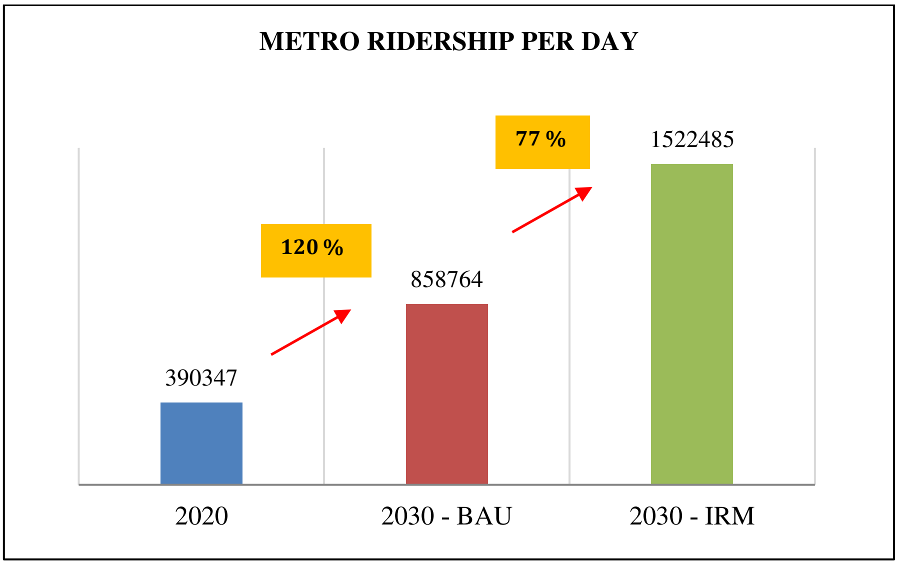


Figure 3. Comparison of Metro Ridership for the years 2020 and 2030

The metro ridership per day for IRM scenario which constitutes of about 203 km of metro network is observed to be 15.2 lakhs. Hence, with further rise in metro network by 34km in addition to 169km, the metro ridership increases by 77% when compared to BAU scenario. From the overall network it was observed that the maximum Passenger Per Hour Per Direction (PPHPD) for the metro network is identified to be 48,425 (Forty-eight thousand four hundred and twenty-five) between whitefield and Ujjwal stations; while, 33,016 (Thirty-three thousand and sixteen) pphpd on the Inner Ring Metro Line between Hosahalli and Padarayanapura stations**.** Consequently, 24,477 (Twenty-four thousand four hundred and seventy-seven) pphpd is observed in the Yeshwanthpur-Sandal Soap Factory-IISC metro stretch.

Trip Assignment

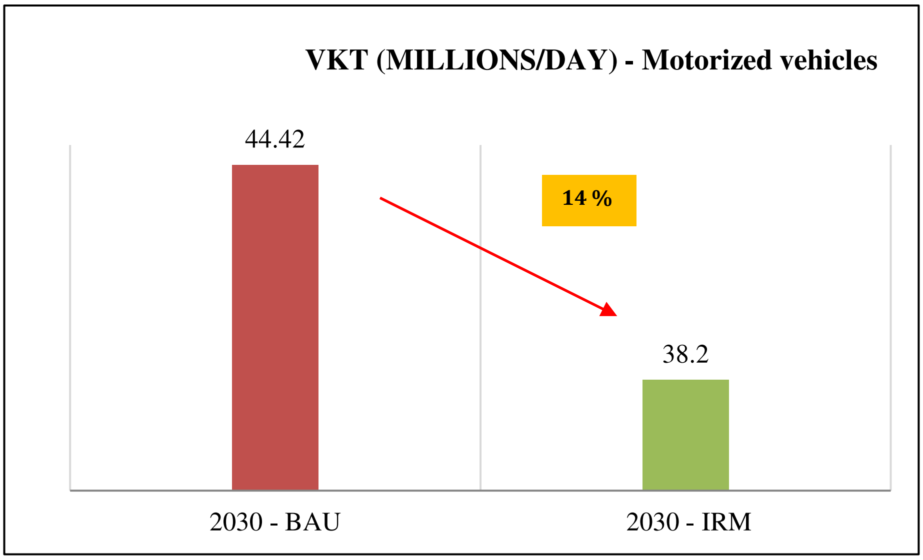


Figure 4. Total Vehicle Kilometres Travelled in 2030 for BAU and IRM scenario

User equilibrium trip assignment method is used to assign the trips onto the road network. Vehicle Kilometres Travelled (VKT), road link volume and Volume to Capacity (V/C) are estimated for the scenarios defined by updating the road network. The VKT estimated for the future year is presented in Figure 4. There is 14% reduction in the total VKT with the addition of Inner Ring Metro Line of 34km, which is majorly due to the decline in the utilization of private transport modes and increment in the modal shift towards metro corridor. There is almost 5 times increase in the VKT of metro in IRM scenario when compared to BAU scenario in 2030.

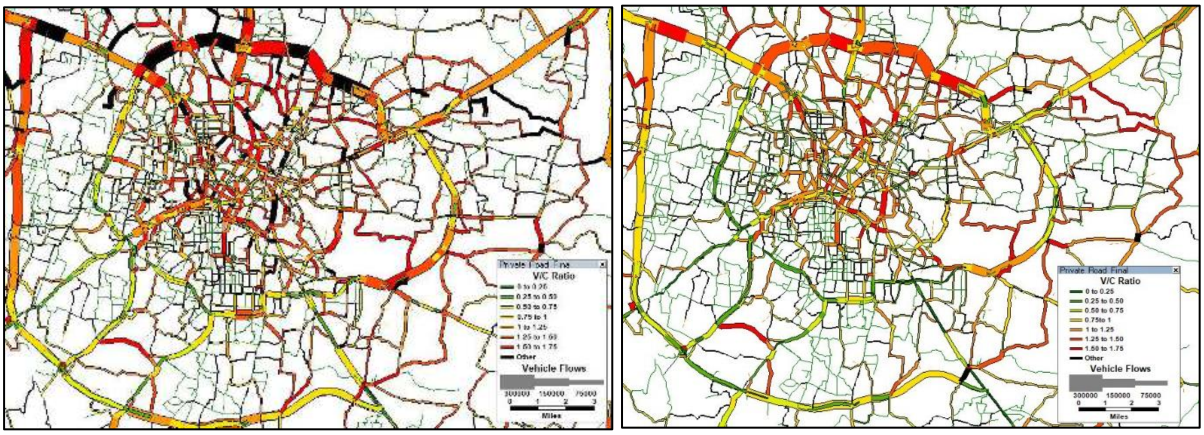
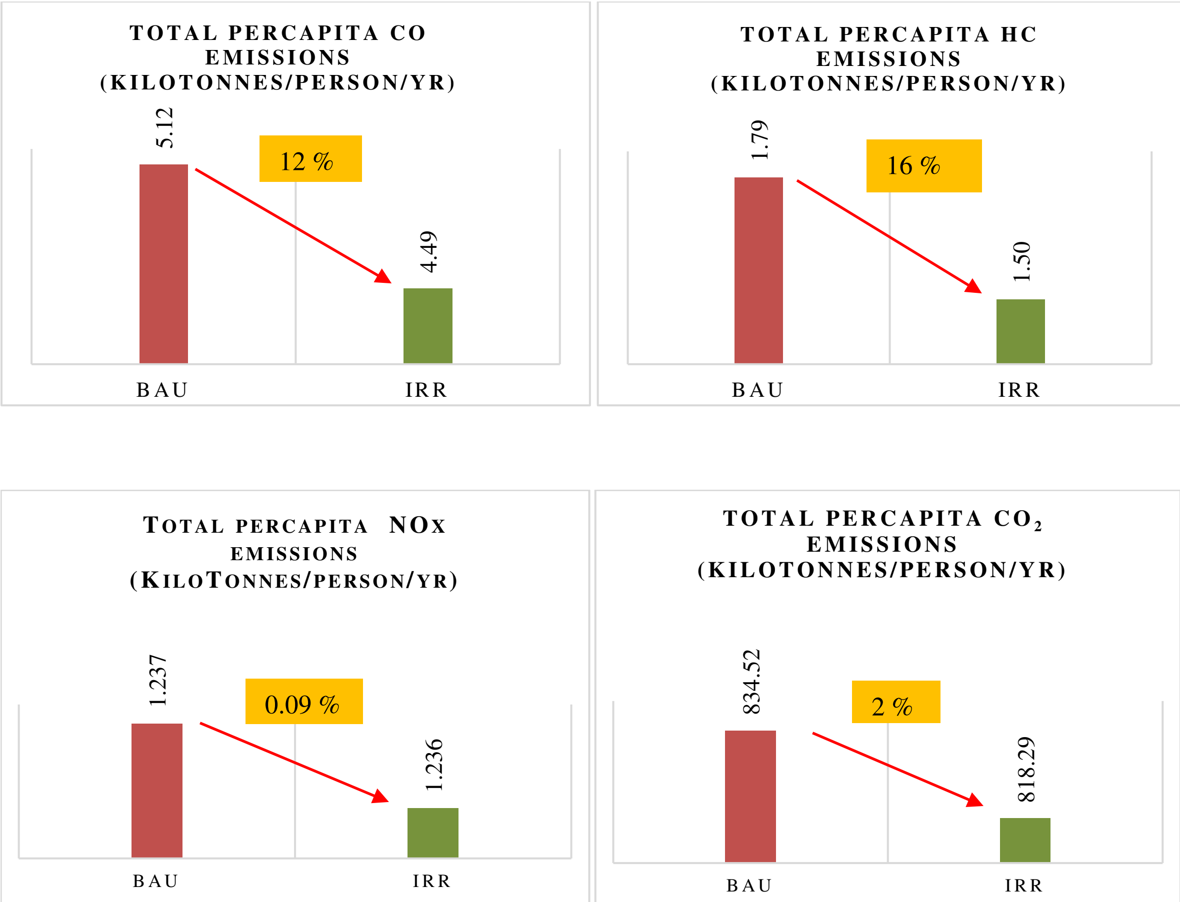


Figure 5. Trip Assignment of Vehicles in 2030 for BAU and IRM Scenarios

Figure 5 describes the Volume/Capacity (V/C) on the road and the metro network for the projected scenarios. It can be observed that a greater number of trips are shifted onto metro network which will eventually result in declining the traffic congestion on roads. The darker lines signify heavily congested links and the lighter lines signify the links with less congestion. The IRM scenario clearly shows the reduction in levels of congestion on the ring road due to a significant shift to metro. Similarly, the central section of the city is well connected with IRM because of which the darker lines turned lighted signifying less congestion.

Estimation of Emissions for BAU Scenario and IRM Scenario

The emission factors for BS-VI vehicles are assumed using vintage of the vehicles and the technology have been used to estimate the average emission factors for each vehicle type. The total percapita emission of five pollutants namely CO, HC, NO_x, CO_2 and PM are estimated using the emission factors derived by Chandel et. al. 2018 *(Refer appendix)*. For electric vehicles, emission factors for four different energy mix scenarios was reported by Chandel et. al. 2018; however, in this study, only BAU emission scenario is considered and the emissions plots are presented in figures 6. In BAU emissions scenario, the electricity grid mix for future, horizon years, is taken from IEA (2015) that is 74% and 26% of electricity will be generated from Non-renewable sources and renewable Sources respectively. The total percapita emissions plots depict that there is significant reduction in the emission of CO, HC, NO_x, PM and CO_2 pollutants. The 4% decrease in the total percapita emission of CO_2 pollutant in IRM scenario is because of the increased ridership of metro. It is to be noted that emissions from metro are considered to be indirect emissions. Metro does not directly emit pollutants when it runs but, the process involved in electricity generation required to run metro causes emissions. Even though the electricity generation emissions are happening at a different location, they are attributed to the city's transport emissions.



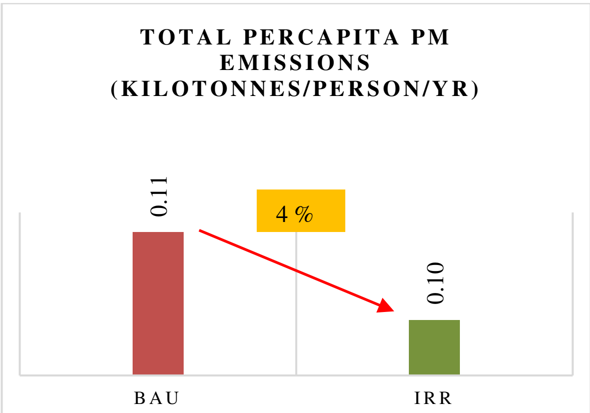


Figure 6. Total Percapita Emissions in 2030 for BAU and IRM Scenario

Even though there is fluctuation in the mode wise percapita emissions, significant decrease in the emission is observed for all pollutants in 2030 IRM scenario.

Estimation of Fuel Consumption for BAU Scenario and IRM Scenario

Mode wise and total vehicular fuel consumption by car, two-wheeler and bus is estimated for BAU and IRM scenario in 2030. The plots showing the variation in fuel consumption for the considered scenario is given in figures 7 and 8, respectively.

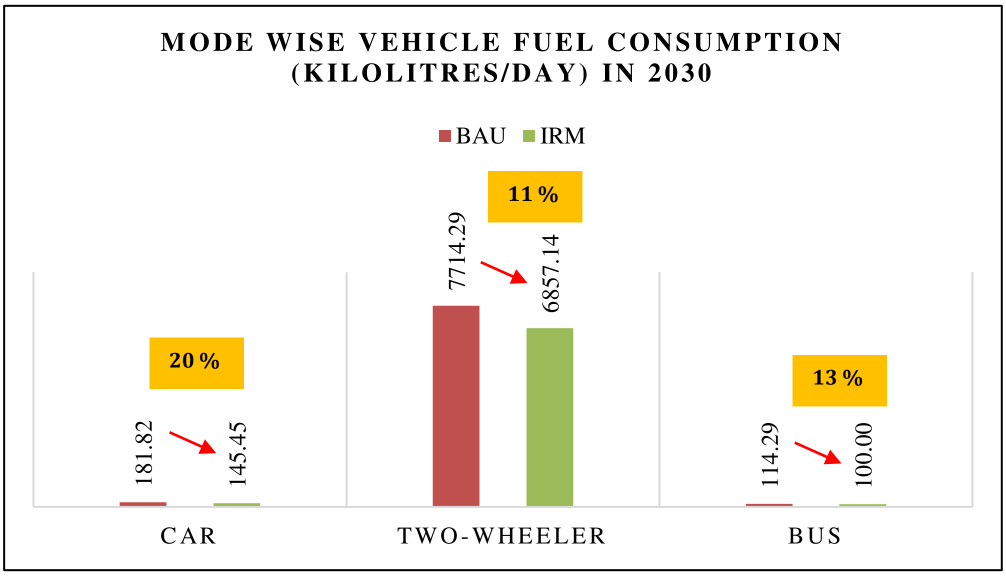


Figure 7. Mode wise Vehicular Fuel Consumption in 2030 for BAU and IRM Scenario

The mode wise fuel consumption is decreasing by 20%, 11% and 13% for car, two-wheeler, and bus from BAU scenario to Inner Ring Metro scenario. This is mainly due to the reduction in VKT by private modes, especially car and two-wheeler.

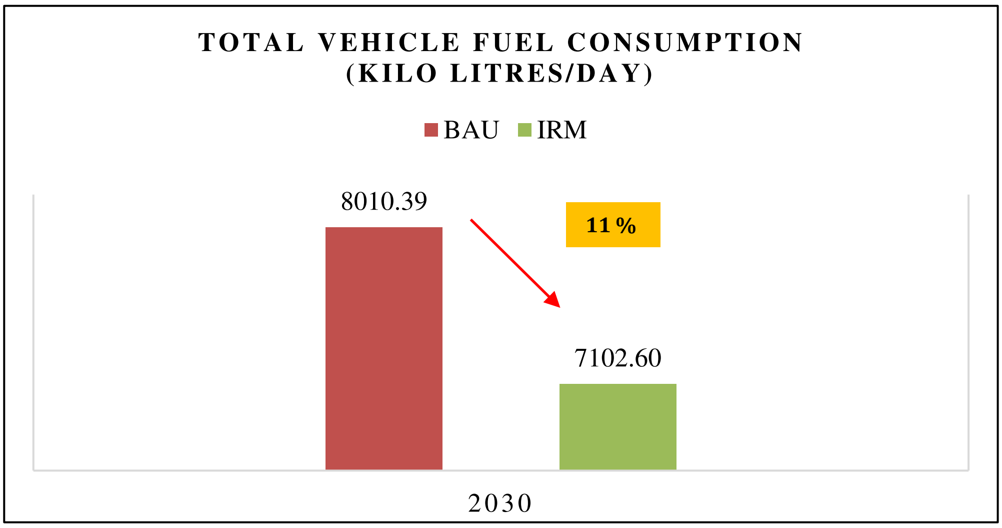


Figure 8. Total Vehicular Fuel Consumption in 2030 for BAU and IRM Scenario

Furthermore, 11% decline in the fuel consumption in IRM scenario is observed due to sizeable modal shift towards electricity-based metro in conjunction with increase in the metro network coverage.

Summary and Conclusions:

- Addition of IRM to the BAU metro network for the year 2030 is increasing the coverage of metro further leading to a significant increase in the metro ridership. It was observed that there is 77% ridership growth in IRM scenario with respect to BAU 2030 scenario.
- The BAU metro network along with IRM network will create a total metro network length of 203 km with the maximum ridership of 48,425 pphpd between whitefield and Ujjwal stations. The maximum ridership on IRM line is estimated to be 33,016 pphpd between the stations Hosahalli and Padarayanapura and the ridership between sandal soap factory station and Indian Institute of Science (IISc) station is 24,477 pphpd in 2030.
- 14% reduction in VKT is observed with adding 34 km IRM stretch with 13 interchanges when compared to 169 km metro network in 2030 BAU scenario which is mainly due to Push and Pull Effect i.e. more number of trips by private modes are shifting towards metro with increase in the network coverage in the city level; thereby, reducing the congestion at city level.
- The total CO_2 emissions in the IRM scenario are higher than the BAU 2030 scenario. This is due to high emission factor values of metro when compared with other modes. However, the total percapita CO_2 emissions are less in IRM scenario than BAU 2030 scenario due to ridership shift to metro.
- There is a 11% decline in the fuel consumption in IRM scenario is observed due to sizeable modal shift towards electricity-based metro in conjunction with increase in the metro network coverage.
- The metro network in 2030 will cover the locations which are heavily employed and also congested like the Electronic city, Outer ring road, Whitefield. Providing metro network on these lines is considerably reducing the congestions levels.
- It was also observed that the ridership per hour per direction on the outer ring section are above 40,000 pphpd and close to the maximum ridership per hour per direction.
- The assumption used in the modelling is that 6 coaches train with maximum capacity of 69,000 pphpd will be plying on the metro network; thus, IRM metro line can ply almost with 50% of its capacity in the year 2030 itself.

From this study it is seen that the mode shares of car and two wheelers in IRM 2030 scenario are less than BAU 2020 scenario. This is because IRM is filling the important missing link in an ideal spider network for a circular city like Bengaluru which is growing radially. This network is enabling easy and more direct travel between any two points in the city using the combination of ring and radial lines rather than people having to travel all along the radial line up to majestic and then transfer to another radial line. This is the reason for which the quantified impact of IRM is quite substantial in terms of increase in mode share of overall PT, reduction in percapita emissions and reduction in fossil fuel consumption. It can also be concluded from this study that providing metro network on high density corridors with more number of round trips can make metro an attractive mode of travel for commuters thereby reducing emissions and congestion and improving overall quality of life.

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Acknowledgement

We thank you Bangalore Metropolitan Rail Corporation Limited (BMRCL) for providing information regarding data required for analysis. We also thank you Indian Institute of Science (IISc) for all the support for conducting the analysis.

Appendix

Table A: Emission Factors for Conventional Vehicles (gm/km)

Emission Factors (gm/km) - 2031					
MODE/Pollutant	**CO**	**HC**	**NOx**	**CO_2**	**PM**
Bus	2.8774	0.2023	1.3189	611.151	0.0225
Car	0.528	0.133	0.13	144.29	0.004
Auto	0.487	0.316	0.147	81.74	0.017
Two-wheeler	0.933	0.201	0.057	42.709	0.011
Metro	6.479	0.0012	24.905	14079.57	1.767

(Source: Estimation of Emission Factors for Different Vehicles, IITB 2018)

***Preferred Citation of this technical article*:**

Verma A., Vajjarapu H., Allirani H. (2020), "Ridership Estimation and Evaluation of the Proposed Inner Ring Metro Corridor in Bengaluru City", Un-Published Technical Article, Transportation Engg. Lab., Dept. of Civil Engg., IISc Bangalore.