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Connectivity Analysis and Feasibility Assessment of Proposed Metro Network Expansion in Indore City for Sustainable Urban Mobility

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Abstract: This study investigates the existing gaps and future prospects in metro rail connectivity across Indore city, focusing on enhancing accessibility to high-density land uses and socio-economically important areas. Analysis reveals that the south-east and south-west sectors, characterized by concentrated residential clusters, major commercial hubs, and essential facilities, remain under-served in terms of metro infrastructure. A semi-circular ring metro link is proposed to bridge this connectivity gap, providing enhanced linkages from key nodes like the airport to Rajendra Nagar and extending service to peripheral villages such as Sirpur, Bank, Ahirkhedi, and Sukhniwas, while integrating critical urban infrastructure like the Regional Park and Central Advanced Technology center. Additionally, a new corridor is recommended for the south-eastern region to cater to emerging PSP hubs and peri-urban villages, offering affordable transport options along Ring Road-3. The feasibility analysis indicates that approximately 49% of urban wards are directly served by metro stations, while 45% of wards exhibit high feasibility for metro development based on land use and density factors. Connectivity assessment shows that 35% of stations facilitate direct access to vital urban functions, whereas 38% link urban fringes to the central business district (CBD). However, 13% of proposed stations are located where road transport remains a more feasible alternative. Land acquisition emerges as a key constraint, with 54% of land within a 500 m buffer requiring private acquisition for surface alignment, while underground corridors are limited to 9.8% of the proposed network. Furthermore, the extension of metro services to Dewas, an industrial hub approximately 25 km from Indore, is proposed to support regional economic integration and reduce surface traffic congestion. Overall, this research provides a comprehensive framework for sustainable metro planning in Indore, balancing accessibility, feasibility, land acquisition challenges, and long-term urban mobility needs..

Keywords: *Indore metro connectivity; Feasibility analysis; Urban transport planning; Land use integration; Metro network optimization; Sustainable mobility; Land acquisition; Peripheral connectivity; Dewas corridor; Public transportation infrastructure.*

1. Introduction

Indore is the commercial city of Madhya Pradesh, is one of the fastest growing city in India with a population of 2.5 million reported in the Census of India 2011. The city transport until recently depends almost entirely on the roads as the sole mode of transportation. The existing road network within urban agglomeration is 1710km. The city depends on various modes of local transports, this includes Auto rickshaw, Vans and Tata Magic. Many private Cab Services also operate in the city such as Ola Cabs, TaxiForSure, Meru Cabs, UBER and Chartered Cabs. The city population was projected to grow by 3.6 million in 2021 and 4.9 million by 2041, considering the fast growing population, the city requires Intelligent Transport Transit System. Jawahar Lal Nehru Urban Renewable Mission (JNNURM) was launched in 2005 which focuses to improve urban transportation services to provide effective linkages and connectivity; this helped in scaling up local transportation by introducing Bus Rapid Transit System (BRTS).The Indore Bus Rapid Transit System (BRTS) was started in 2013. On the basis of travel demand pattern and road network characteristics, seven BRTS corridors were proposed. Amongst seven AB Road pilot corridor has been completed, it runs along 11.7 km and caters to around more than 70,000 passengers daily(BRTS, JNNURM).The cumulative figure of registered private and Govt. vehicles are 2081091 (www.mptransport.org).The increase in road length is not at par with phenomenal growth in the number of vehicles on the road. The BRTS could not cope up with transport demand of fast growing population and commercial activity of the city. There fore, the need for metro as a rapid transit light metro system was felt. The total metro system consists of 6 corridors covering a distance of 104.26kilometers. There will be three types of run – on road, elevated, at grade and underground in some locations. It is estimated that the total load of metro rail is around 1, 90,000 passengers daily(DPR for MRTS, GoI). The study carried out feasibility of Metro rail by analyzing all potential factors. This study depicts landuse wise, ward wise and public asset wise feasibility study of Indore Metro as well as Metro route impact analysis for the projected population of year 2031.Thestudy portrays feasibility of metro rail in terms of transport services and social benefits for future scenario after implementation of metro rail project. It also helps to redefine routes to provide maximum benefits to commercial and economic zones of the city.

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2. Materials and Methodology

2.1 Materials

Indore is the most populous city of the Indian state of Madhya Pradesh. It is also knows as commercial capital of the state and comes under tier 2 cities in India. Indore is situated on fertile Malwa plateau, located at 22º 43.2N latitude and 75º51.4E longitudes. An average altitude of city is 550meters above MSL. The planning area of Indore city covers 505.25sq km land area and lies in Kanh river basin. The river and its distributaries traverse through the densely populated area of the city. The city enjoys a composite climate with three distinct dry, wet and cold seasons. The mean daily temperature is about 25.1ºC throughout the year. Figure 1 depicts regional location map of Indore planning area. Kompsat(PAN/Multispectral) satellite data of March 2013interpreted visually to prepare transport network and landuse map of the study area, keeping in the view recent developments as well as future development trends which would be implemented as proposals in development plan.

Indore metro rail alignment, route and station data has been collected from Indore Metro Rail Authority. Population and other statistical data have been taken from Census 2011 and City Development Plan (CDP) Indore. Ward maps prepared by Municipal Corporation Indore and Khasra maps prepared by Land Records department have been utilized for the present study. Locational public asset data is collected using GPS and segregated into various categories as per their use. All above information has been correlated and analyzed on the GIS environment using Arc GIS software.

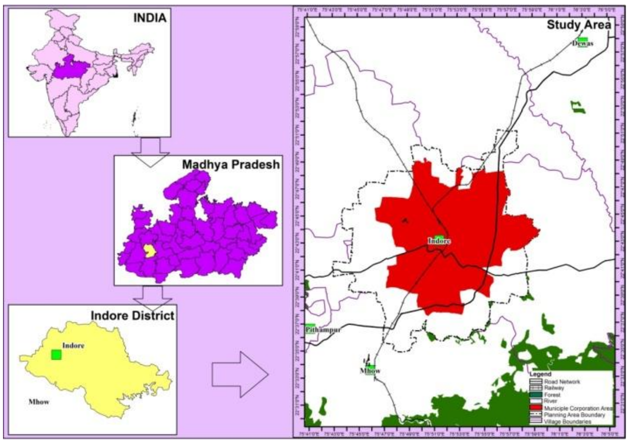


Fig 1: Regional Location Map

2.2 Methodology

2.2.1 Road Network Analysis: The road network plays an important role in the economic development of a city; therefore, the kilometer-age of paved roads existing in a city is often used as an index to assess the extent of its development. The road network within the Urban Local Body (ULB) not only reduces the cost, but also is economically viable and time saving. Connectivity to Special Economic Zone (SEZ) depends on off road network of sectors influencing economic activities [V. Batsos And John Tzouvadakis(2011)]. The length of major road arteries in Indore is nearly 739 km. The Main Roads (45m/30m/24m) cover a length of 233km, while Sectoral Roads (18m) and Sub Sectoral Roads cover (12m) a length of 136 km and 202 km respectively. The National Highway and State Highway (75m/60m/45m) covers 169 km length and accounts for more than 50% of the incoming and outgoing traffic in the city. These roads carry majority of traffic but have insufficient carriageway width(Indore Municipal Corporation 2012).The railway track virtually divides the city into two parts acting as one of the constraints to mobility of vehicle in the city. The rapid development coupled with increase in population has contributed an increase in vehicular traffic on roads and this resulted in surge of number of problems like road congestion, delay in transit, accidents etc. Consequently, in the proportion of development of the city, road network was also proposed for the year 2021.The proposed main road lengths are 110 km, named MR1 to MR11. The length of proposed sector and sub sector road is 236 km and 230 km respectively. Existing and proposed transportation network for the year 2021 exhibits in figure 2.

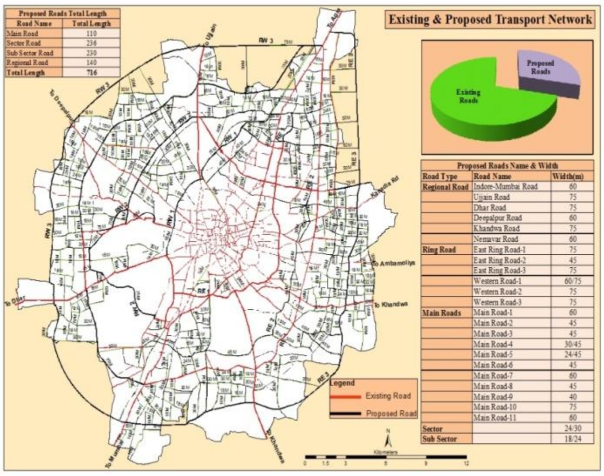


Fig 2: Existing & Proposed Transport Network

2.2.2 Landuse: Rapid development along with demographic change is the most direct influencing factor on urbanization and urban change, which further appear as land use & land cover change in urban centers. Landuse encompassing various controls on public transport[Bertaud, A (2011)],the empirical study of existing and proposed landuse for metro rail services has been carried out. The development within the planning area proposed by Town & Country Planning (T&CP), effective till 2021, considered for this study. The development plan divulges existing landuse in different classes i.e. Residential, Commercial, Industrial a Recreational etc. Although, the metro rail was not proposed in the development plan 2021, but it is integrated in cadastral based landuse for this study. Moreover, the development plan provides the future development scope of the city which seeks to order and regulate land use in an efficient and ethical way to prevent landuse conflicts. Thus, the plan also illustrates proposed area under various landuse classes for probable population growth for the year 2021(Fig.3 &Table1).Spatial coverage of existing and proposed landuse as per the development plan represents in figure 4a &4b.

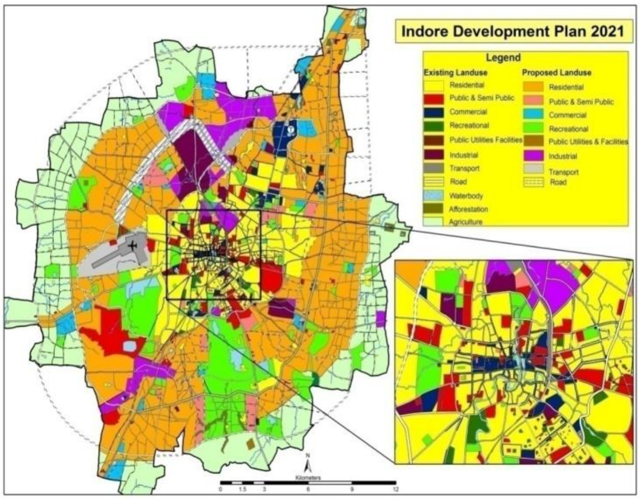


Fig 3: Indore Development Plan 2021

Table 1:Area Statistic Indore Development Plan 2021

Landuse Category	Area in ha	
	Existing Landuse	Proposed Landuse
Residential	4904	15822
PSP	1807	859
Commercial	762	847
Recreational	154	4523
Transport	3077	3842
PUF	49	35
Industrial	1103	1787

Source: Indore Development Plan 2021

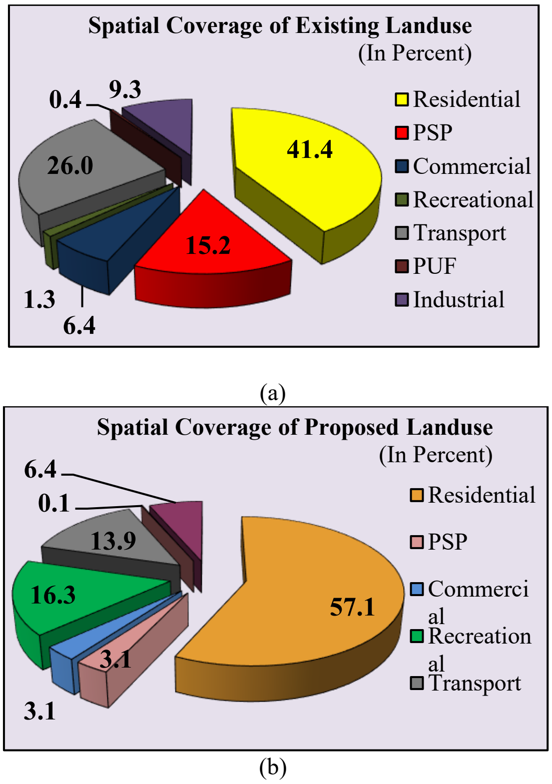


Fig 4 Spatial Coverage (a)Existing (b) Proposed

2.2.3 Municipal Wards: The feasibility analysis on Metro Rail is mainly focused on Indore Municipal Corporation (IMC), as the municipal area occupies maximum activities of the urban centers. Different IMC wards have various existing and proposed landuse activities. Moreover, feasibility of metro services depends on landuse activity which is regulated by the population in wards. The Indore Municipal Corporation area consists of 82 wards and covers an area of 27174 ha. This is 54 percent of planning area of development plan 2021.A total of 73 stations of Indore Metro were proposed, out of which 67 falls in IMC area. The landuse activities differ from ward to ward which gives significant impact on feasibility analysis for metro uses. Therefore, the ward wise landuse distribution of activities prompt uses like residential, commercial, transport etc. the calculation is shown in figure 5.Metro rail passes through almost all IMC wards except few. The accessibility to metro stations for travelers from these wards plays significant role in this study. Therefore, the distance of nearest metro station from their concerning wards has been calculated through network analysis in GIS. The ward wise accumulation of metro stations and their utmost probable travel distance is present in table 2.The ward number 01, 36, 51,76,83,84 and 85 are untouched by metro railway while ward number 85and 40 does not having any station.

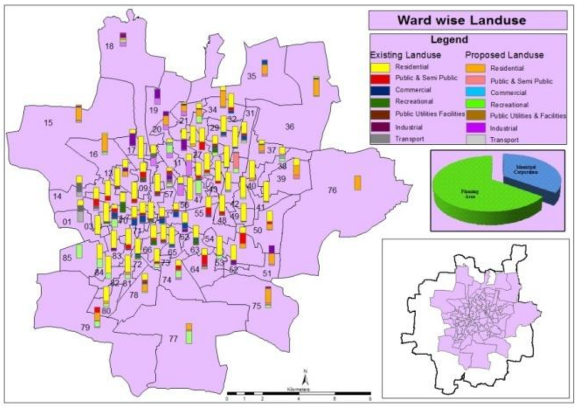


Fig 5: Ward wise Landuse Distribution

Table 2: Area Statistic Indore Development Plan 2021

Ward No.	No. of metro stations	Probable travel distance (in km)	Ward No.	No. of metro stations	Probable travel distance (in km)	Ward No.	No. of metro stations	Probable Traveldistance (in km)
1	0	4.5	3	1	1	5	3	0.9
2	0	2.5	3	3	1.58	5	3	0.5
3	0	1.8	3	0	1.6	6	2	0.8
4	3	1.4	3	0	1.5	6	0	1.4
5	0	2	3	1	2.45	6	1	1.8
6	1	1.3	3	2	4.55	6	2	0.6
7	1	2	3	0	7.4	6	4	1.25
8	1	0.8	3	0	2.8	6	1	1.5
9	0	2	3	0	4.48	6	0	1.7
10	1	0.8	3	0	2.75	6	0	1.5
11	0	2.2	4	0	1.8	6	0	1.39
12	0	1.2	4	2	1.3	6	0	1.4
13	0	3.2	4	1	1.8	7	0	2.58
14	1	3	4	2	1.5	7	0	1.3
15	6	3.5	4	0	0.8	7	1	2.23
16	0	3.3	4	1	1.1	7	2	1.5
17	0	2.3	4	0	1.7	7	4	1.3
18	4	1.4	4	3	1.6	7	1	6.2
19	2	1.9	4	0	2.3	7	1	6.3

20	0	1.6	4	0	1.8	7	1	4
21	2	1.6	5	1	3.4	7	1	2.46
22	1	0.6	5	0	4.5	7	2	4.7
23	1	0.5	5	0	1.7	8	0	2.5
24	1	0.8	5	0	1.3	8	2	2.5
25	1	1.8	5	0	4	8	0	2.5
26	0	1.4	5	0	3.12	8	0	2.15
27	1	1.6	5	2	1.2	8	0	3.25
28	1	1.4	5	3	1.34	8	0	5.17
29	3	1.5						

Source: Census 2011

2.2.4 Population projection: Progression of a city attracts population from major parts in addition to existing population. Indore because of its central geographic location is a part of Indore, Dewas, Ujjain Industrial- Commercial Corridor and it is also apart of special economic zone so it attracts surrounding population for the purpose of livelihood. In order to cater the needs of such enormous population, demand of transport is high for an un-interrupted flow of goods and services. In such situations, origin and destination needs in terms of population must be satisfied sufficiently in all aspects. Therefore, the population projection of urban centre for a fixed time interval has a significant role to fulfill the future needs. It gives a perceptive growth trend of population along with time. To attain this objective, Census data up to the year 2011 is used for present analysis. Table 3 exhibits the population trends in Indore planning area as decadal population from 1981 to 2011, their variation and growth rate. The population of Indore city is increased from 8.29lakh in the year 1981 to 2.5 million in 2011.An average growth rate in city from 1991 to 2011 has been of the order of 40% approximate. Thus, the average increase has been higher as compared to national growth rate (@22%), which can be attributed mainly to the rapid urbanization of the city (city development report).The population projection for Municipal area and Indore planning area for the year 2021 and 2031has been calculated by standard projections methods. Arithmetic and geometric methods considered for the projections. As the study is concerned with the feasibility analysis of metro rail, which routed from municipal wards, therefore the population residing in wards plays a key role in the analysis. Thus, the ward wise population and their density has been also evaluated (table 4).

Table 3: Population Trends in Indore Planning Area

Year	Indore Municipal Corporation (IMC)			Indore Planning Area		
	Population	Decadal Variations	Growth Rate %	Population	Decadal Variations	Growth Rate %
1981	829327			884775		
1991	1091618	262291	31.63	1189797	305022	34.47
2001	1506062	414444	37.97	1698474	508677	42.75
2011	2196090	690028	45.82	2534685	836211	49.23
2021	2982849	Projected		3576742	Projected	
2031	3947321			4925989		

Table 4: Ward wise Population in Indore IMC

Ward Number	Population	Population density	Ward Number	Population	Population density
1	29560	103	44	24176	424
2	28559	1020	45	23337	376
3	28963	221	46	24260	866
4	26216	203	47	24875	130
5	28559	362	48	22201	207
6	28321	311	49	24374	224
7	26477	265	50	27699	56
8	28855	902	51	26300	117
9	27579	221	52	23356	389
10	25639	377	53	29108	493
11	25503	232	54	27762	73
12	26119	358	55	22167	72
13	27979	163	56	28918	230
14	27446	81	57	23221	98
15	29019	12	58	29524	273
16	29058	67	59	22444	321
17	29557	214	60	24025	329
18	29288	23	61	23067	659
19	26724	47	62	22170	274
20	24975	185	63	22085	157
21	22381	97	64	29645	104
22	22305	455	65	29245	308
23	26782	239	66	25886	171
24	24431	284	67	22447	478
25	23615	363	68	22058	959
26	22051	1297	69	25596	267
27	24645	211	70	25805	266
28	24630	265	71	23565	184
29	23832	123	72	23436	197
30	25953	208	73	23939	303
31	22824	105	74	29468	75
32	21957	213	75	27321	23
33	22621	215	76	22202	8
34	23145	97	77	29626	13
35	24337	18	78	29687	70
36	22509	13	79	29664	16
37	22117	74	80	29658	160
38	28846	152	81	29438	206
39	29492	73	82	29436	237
40	23517	258	83	29669	193
41	25171	180	84	27412	397
42	22448	153	85	29669	84
43	22144	207			

Source: Indore Municipal Corporation

2.2.5 Asset Inventory

In the study of traveler's feasibility for use of metro services, residential and other landuses are considered. Public places are the direct indicator of frequently visited sites. The feasibility of metro stations in relation to public assets is one of the important aspects of this study. The asset inventory analysis provides a complete and detailed inventory of the point assets existing in Indore Planning area. Asset information has been collected through detailed GPS survey. Asset classes and types provide a base for the initial establishment of the asset inventory. Moreover, assets density is calculated to find out the feasibility of metro stations for travelers from different asset clusters (Fig.6).The probable distance between the asset and their nearest metro station is found out using network analysis tool in GIS.

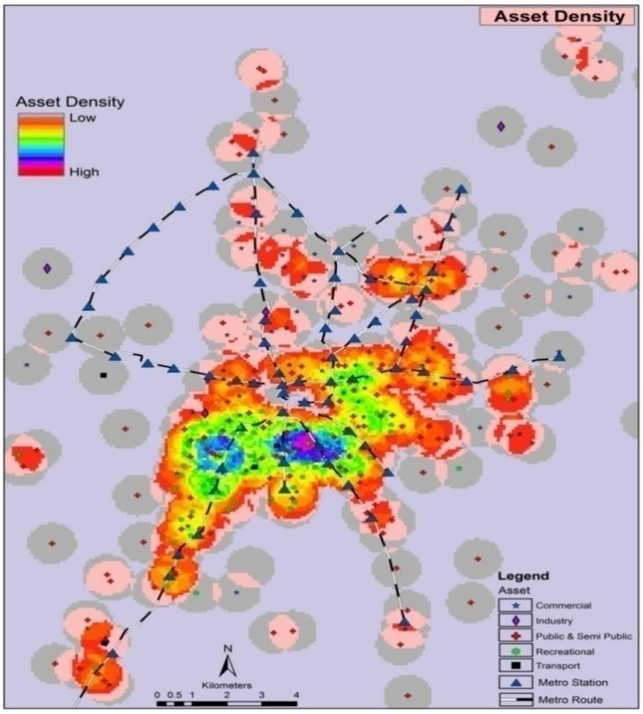


Fig 6: Asset Density

2.2.6 Metro Station Location Assessment: The path of a metro rail line includes the examination of factors such as topological configuration, quantity of stations and lines, frequency of lines and pricing(Marvna and Garcva; 2009). The number of travelers, the demand period of parking time around the station, as well as pedestrians accessibility to the station, are differential variables regarding whether a probable traveler will be attracted to use the metro or not. The Indore metro has 73 stations from different urban nodes. To evaluate the station locations in terms of urban growth and aid, metro stations have been classified under class I, II and III (fig.7). Station locations that enable access to health, education, entertainment, commercial services and provide connection to other railway stations, preferably chosen under class I. Class II exhibits the intersection points of metro rail and other major roads. The station locations under class II illustrates the junctions where other transportation services like BRTS and other services will be more feasible for travelers in contrast of metro rail services. The station which covers the outer area and give connectivity to urban periphery categorized under class III. These classes give a clear cut line of frame for future development and urban growth. These stations will attract or serve a larger number of travelers after development as proposed in development plan but presently they show only the linear expansion of metro rail.

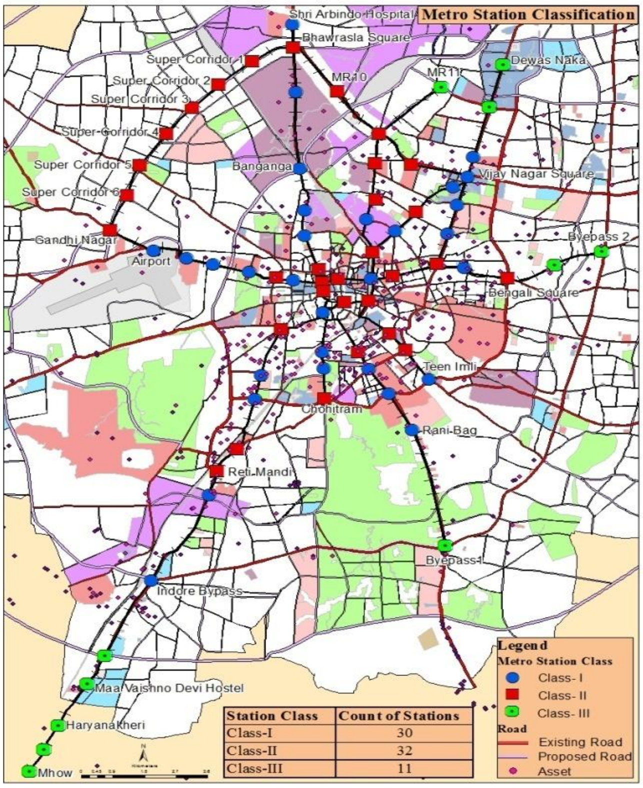


Fig 7 Metro Station Classification: Metro Station Classification

2.2.7 Proximity Analysis: The city transit systems function as nodes for development in urban environment. The area accessibility and the use of that area, contribute to travelers load in respective nodes, as well as the surrounding area is also benefited by the metro services. This facilitates growth of agglomeration activities. Singapore facilitated "highest and best" use of land by increasing the land use density around transit stations, subsidizing public transport ridership and adopting congestion pricing [Yang and Lew (2009)]. In Hong Kong, integration of transport and land use policies has promoted high-density development around transit stations, generating in the process significant revenues which help finance mass public transit as well as ridership[Lo, Tang and Wang (2008)]. These forms of transit oriented development are sustainable because of the focus on high capacity mass transit, high densities, and lowering reliance on private automobiles [Cervero and Murakami (2009)].The analysis gives bidirectional view on the relation between specific spatial clusters around the nodes and metro stations. The travelers from area which comes under 500 m distance from metro station will be more viable and frequent users of metro services. The landuses of these clusters will portrait the utilization of this service. Therefore, Metro station proximity is addressed as considering the landuse of areas coming under 500 m closer to the station. This analysis excludes the clusters of landuses to find out the more practicable areas for metro services. Statistical and pictorial view of more contributed and affected landuses shown in figure 8.

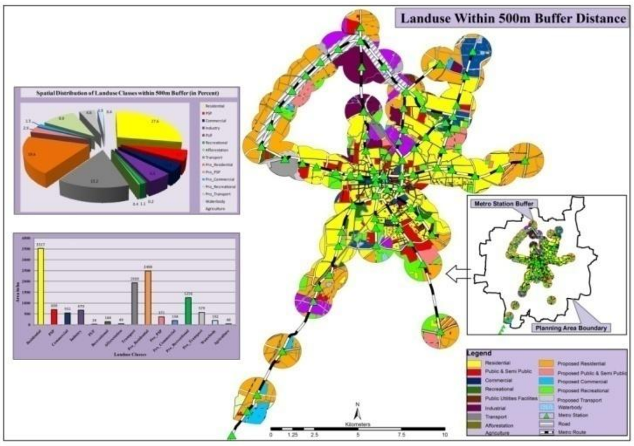


Fig 8: Landuse Proximity

2.2.8 Social and Environmental Impact analysis: One of the most important aims for the improvement of public sector amenities according to Shen et al is to fulfill the social objectives, which should be addressed in all public projects(Khashayar, Kashani, Jou).The potential social impacts, which are expected from the existence and the operation of metro could be divided into three categories, namely socio-economic efficiency (passenger time savings, reduction in traffic congestion, cost saving to society), development plan of the city (increase in productivity, efficiently function of urban areas, urban development) and social improvements (access for all people, land acquisition). As availability of land for land acquisition plays major role in urban centers but at the same time it has social impacts at the time of acquisition by the local bodies. Therefore, land acquisition and ownership analysis is taken up to identify availability of private and government land within the buffer area under 500m along the metro track(fig.9).The proposed metro has six corridors under phase I, II & III with total expanded length of 104.26km.Type of Metro travel and stations contribute in minimizing the negative effects of environmental pollution. Noise pollution is minimized in underground transport infrastructure compared with elevated and surface ones. Thus, the ratio of underground travel, elevated travel, ramp and surface travel also compared to avoid the redundant noise pollution (figure 10a & 10b, table 5). Metro rail route and position depicted in figure 11.

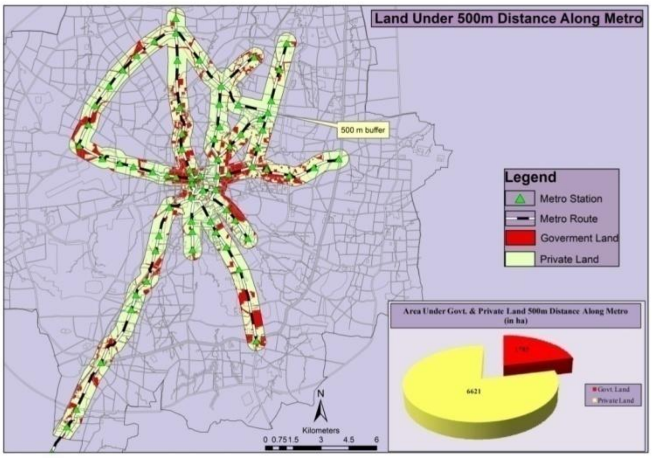
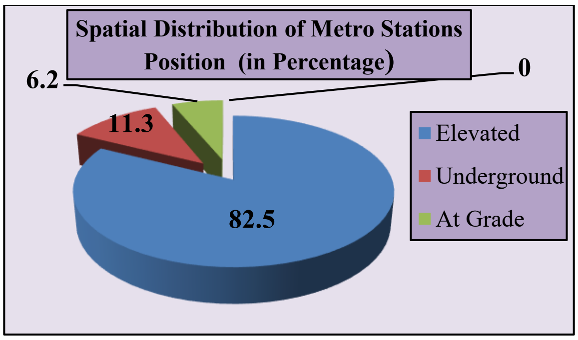


Fig 9: Government & Non Government Land

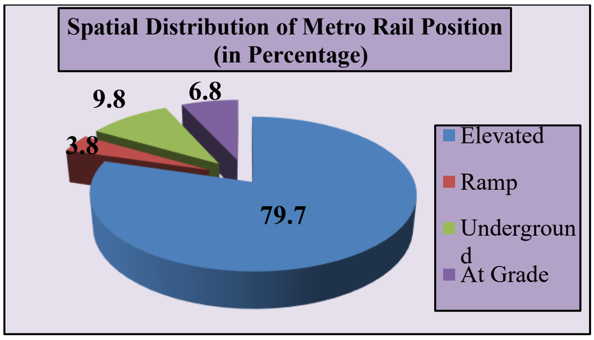
Table 5: Position of Metro Stations & Lines

Phase	Line No.	Total Stations				Length in Km				
		Elevated	Underground	At Grade	Total	Elevated	Ramp	Underground	At Grade	Total
Phase I	3	20	4	6	30	19.27	1.97	3.22	7.09	31.55
Phase II	2	25	2	0	27	27.21	0.5	1.9	0	29.61
	3S	4	0	0	4	3.6	0	0	0	3.6
Phase III	1	14	4	0	18	15.22	0.59	3.31	0	19.12
	1B	3	0	0	3	3.09	0.3	0.44	0	3.83
	4	14	1	0	15	14.66	0.55	1.34	0	16.55
Grand Total		80	11	6	97	83.05	3.91	10.21	7.09	104.26

Source: DPR for MRTS, Indore Metro Rail Project 2016, Government of India



(a)



(b)

Fig. 10 Spatial Distribution of Metro (a) Stations Position (b) Rail Position

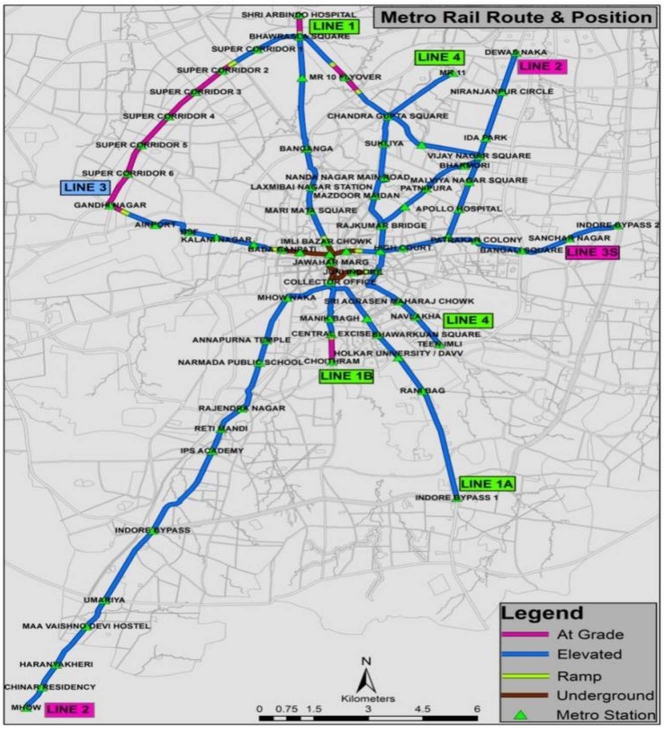


Fig.11: Metro Line Position

2.2.9 Traffic scenario: Like any other major cities in India, Indore also faces many transport problems. Low travel speed, high accident rate involving fatalities and increased vehicular pollution are mainly due to narrow roads with heavy traffic congestion, frequent traffic jams at numerous road intersections and high parking demand due to proliferation of personalized vehicles and over-crowded buses with long routes[Chester, M., Horvath, A. (2008)]. The central area of city has narrow roads and has no place for parking. Usually carriage ways are utilized for parking; this reduces the carrying capacity of road and ultimately increases traffic congestion. Bus terminals which are also located in the densely built areas add to this traffic congestion. To understand traffic scenario year wise vehicular study has been carried out(table 6 & figure 12).The volumes show rapid increase in all modes of transport in past decades. The high increasing trend in vehicle population portrays the perilous future scenario on roads. Thus, for the proper development of city and to provide flawless traffic conditions, planning should be focused on reduction of the traffic load on existing road network through various travel demand management measures. Therefore, emphasis should be placed on viable mass transport system i.e. the Indore metro rail system; it's an optimum and effective solution as per the current day demand for mobility in city.

Table 6: Year wise Commercial &Non Commercial Vehicle Count

S. No.	Year	Non-Commercial Vehicle		Commercial Vehicle			Total Vehicle
		Four Wheeler	Two Wheeler	Goods Carrier	Passenger Vehicle	Utilities Vehicle	
1	2001-2002	No data	48	No data	No data	No data	-
2	2002-2003	2886	27610	1376	1084	217	33173
3	2003-2004	7163	47160	4145	1247	513	60228
4	2004-2005	8581	47632	4851	1359	416	62839
5	2005-2006	15985	60103	11001	2807	673	90569
6	2006-2007	25351	75066	24747	7656	1413	134233
7	2007-2008	36786	93393	27686	17319	2761	177945
8	2008-2009	42451	102795	20213	7454	3087	176000
9	2009-2010	52026	120510	24327	10835	3634	211332
10	2010-2011	56728	138290	26740	9287	3635	234680
11	2011-2012	60524	143612	25208	7451	3803	240598
12	2012-2013	53802	121239	18172	6116	2611	201940
13	2013-2014	50850	139048	17381	5920	3515	216714
14	2014-2015	56722	154858	19159	6416	3685	240840
Grand Total							2081091

Source: DPR for MRTS, Indore Metro Rail Project 2016, Government of India

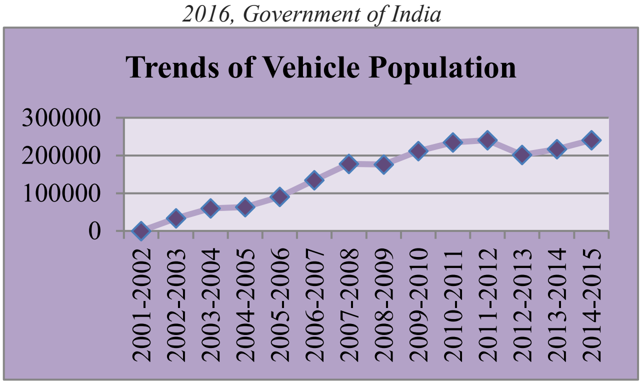


Fig: 12 Trends of Vehicle Poupoulation

3. Result

3.1 Landuse Feasibility

Landuse is one of the fundamental factors while accessing the feasibility of metro in terms of aids and benefits as it directly influences the use of public transport. Indore planning expanded to 50525ha. out of which 11856ha.Land is in existing use and 27715ha land is proposed for 2021 under landuses which directly affects the metro uses. Existing residential covering 44.4percent which further projected to increase 57.1percent by 2021, will act as catalyst on development of Indore planning area. Moreover the metro station feasibility from these areas plays significant role in success of metro project. The flow of passengers is usually from residential areas towards other activities such as PSP, Commercial, Recreational and Industrial. Other activities are resultant outcome of residential dominated areas, so that the metro uses feasibility from these areas to other activity zones like Commercial, Industrial, Recreational, PSP and Transport have been considered.

The analysis depicts proposed metro line provides good connectivity in northern part of the planning area, where as the south-eastern areas do not have sufficient connectivity to metro and also not proportionate to landuse. The feasibility of line 4 is insufficient with respect to landuse and future need of the area. The study also reveals that one more line is required to provide connectivity to PSP hub covering an area 259 ha. and further towards residential area. The south west area is important in terms of various public uses but devoid of any metro connectivity. The area around airport will further developed in residential use which needs metro connectivity. Similarly, missing metro links also observed, which require connecting important PSP i.e. Central Advance Technology, Regional Park and surrounding residential areas.

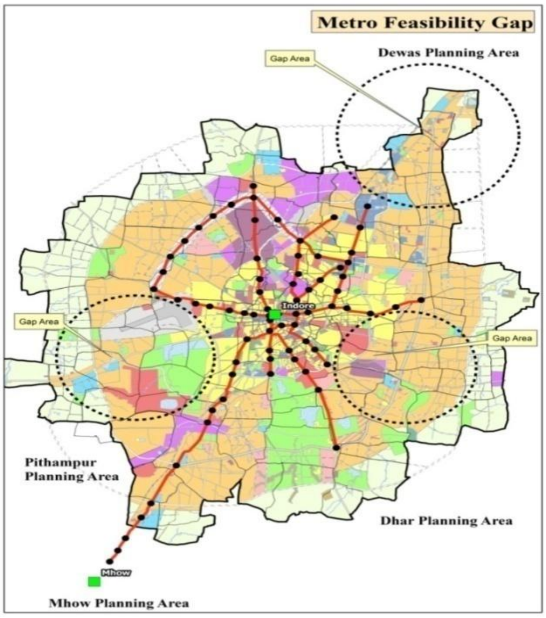


Fig: 12 Metro Feasibility Gap

The metro line 4 connecting airport forming semi circular ring required to be extended towards north east to create a junction point at line 2 near Rajendra Nagar. In northern part of planning area connected with line 4, which is terminated at Dewas Naka. This arm is as important as line 2 connecting Mhow. Indore-Dewas is one of the most important industrial corridor where the industrial work force normally migrates from Indore to Dewas and the commercial work force of Dewas migrates to Indore city. This area is untouched by metro connectivity. Daily traffic load presently meet out using surface transport. The quantum of load therefore needs to be transfer to metro route proposed to extend up to Dewas town. The areas having gap in term of feasibility of metro and need to be reevaluated for public ease, illustrated in figure 12.

3.2 Ward Feasibility:

Wards are most important administrative unit in urban agglomeration. The population density of wards is directly proportionate to landuse activities. Both the factors are important to assess impact on feasibility analysis. The occurrence of Metro stations in a particular ward and travel distance of respective metro station gives a greater convenience to travelers to adopt metro as mode of transport. Therefore, all the factors i.e. population density, landuse, number of metro stations falling in ward and average travel distance to metro station are considered.

Ward wise population density has been sliced between low to high density classes, where minimum population density of 50 person per ha and maximum is > 1000 person per ha are considered. Landuse activities in municipal wards are in different proportions. The percentages of landuse activities which contribute to load of travelers are calculated i.e. residential, commercial, Public &Semi-Public (PSP), recreational and transport. If the ward has a single activity covering more than 75%, then it is assumed that ward is dominated by that particular landuse. In case, ward covering with two dominated activities, it's considered as both activity zones like Residential-Commercial, Residential-PSP etc. If ward covered by more than two activity, it has been considered as a mix landuse. Landuse analysis reveals that37 wards are dominated by residential activity, 1 ward is PSP dominated, 1 ward is Recreational dominated and 4 wards are Industrial dominated. Mix landuse in 39 wards and 3 wards are of residential-commercial use. These landuse classes have been marked high to low grades in terms of contributing the use of metro services. Wards having mix landuse are good feeders to contribute in travelers load, therefore marked higher grades rather than other uses. Similarly, the other wards graded in descending order are Residential-Commercial; Residential; PSP; Industrial and lowest to Recreational.

Number of metro stations varies from 1 to 6 in various wards. There are 23 wards which have1 metro station,11 wards have2 stations, 7 wards have 3, 3 wards have4 metro stations and 1 ward has 6 metro stations. Whereas 44 wards do not have any metro stations, out of which 8 wards are not connected with proposed metro routes. To analyze feasibility of travel distance to reach the respective metro stations, it is assumed that the nearest and farthest distances will certainly affect the travelers load when the traveling distance is more than 3 km. Consequently the average travel distance from wards to their nearest metro station is sliced in six classes i.e. <1, 1-1.5, 1.5-2, 2-2.5, 2.5 -3 and <3. These classes further graded to determine the overall feasibility of various wards. Finally, the feasibility of wards is predicted by combining all above factors. The map has been sliced in 4 classes within municipal corporation area depicted in figure 13. There are 38 wards covering centre part of the municipal area and appear as most feasible.5 wards categorized as moderately feasible, most of these wards are aligned with metro line. There are 18 wards which fall under the less feasible category, these wards are associated with most and moderately feasible wards but depict very less metro connectivity. Analysis demonstrates that4 wards emerge as not feasible in proviso with population density, landuse, number of metro station and travel distance to metro stations.

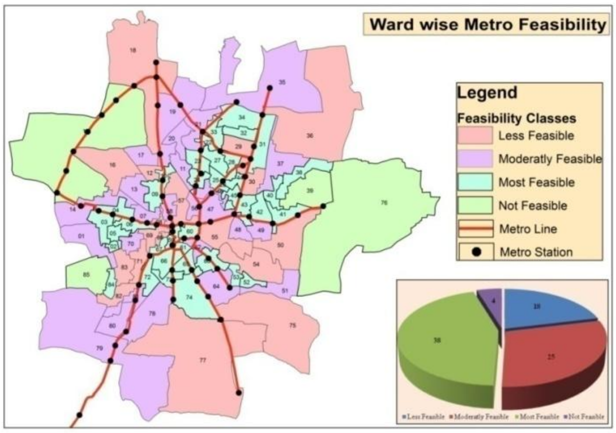


Fig: 13 Ward wise metro feasibility

3.3 Metro Station Feasibility Analysis

In terms of feasibility, the area within the radius of 500 m from metro stations will be more influenced by this service. Intended for, spatial landuse clusters of 500 m have been used. The proximity analysis depicts most of the metro stations surrounded by existing or proposed residential area, which covers 38 percent of total proximity area and 20percent encircled by existing or proposed transport networks. Other existing & proposed activities are comparatively less within 500mproximity. To evaluate the explicit use of various metro stations, they have been categorized under class I, II &III (Fig 7). Out of 85 metro stations 30 stations provides direct connectivity towards major residential, commercial, PSP and recreational facilities. Class II depicts the junctions, where road connectivity is multi-directional and more feasible than metro services. In this case, travelers will be attracted towards use of road facility as mode of transport rather than metro. There are 32 stations which fall under this class. Class III covers 11 stations, which provides connectivity to urban fringes and outer areas to the main city.

The location and density of assets provide a scenario of mobility of travelers within the city and surrounded areas. Therefore, the feasibility of metro in context of assets is also considered, the analysis is supported by the 572 important assets collected in Indore planning area. The Asset inventory analysis reveals high to low density of assets, spreading throughout the planning area. The south-east area depicts numerous high density clusters and distribution of assets, but not connected by metro arm, therefore there is no feasibility. It is suggested to propose one more arm to connect this region. The northern and south-eastern areas also illustrate high density clusters, which are not connected to metro and demonstrate no feasibility for travelers to metro services. These regions are proposed to be connected for future expansion.

3.4 Socio-Environment Feasibility

The population of Indore planning area in the year of 2011 was 2534685 with decadal variation of 836211& growth rate of 49.23. The demographic study shows projected population 3576742 and 4925989 for the year of 2021 and 2031 respectively. The decadal growth rate of last 30 years shows inclined trend and is higher by 14.76 percent in 2011. Similarly, vehicle population graph shows the vertical and simultaneous growth in number of vehicles with years. Therefore, in future number of vehicles will also increase with the proportion of population. Metro is an excellent substitute as it minimizes the dependency on road transport. It has potential social and environmental impacts with various objectives. The land acquisition is one of the important social factors while planning metro routes. The land within 500 m along the metro routes has been analysed from revenue records to obtain information regarding land ownership. The result shows that, 54 percent land is owned by government and rest belongs to private ownership. The spatial distribution analysis shows that, 79.7percent metro lines are planned on elevated pillars; therefore the impact of noise pollution will be less as compared to surface transport. The underground metro lines are 9.8percent, which is passes through the core of the city and therefore reducing noise as well air pollution. 6.8 percent metro lines are proposed at grade position and 3.8 on the ramp, thus the effect of these positions is negative on environment.

4. Conclusion

It has been observed that south-east and south-west parts of Indore city, which have major landuses and high density asset clusters, is grey area in terms of metro connectivity. In southwest part, connectivity between two main locations i.e. Airports to Rajendra Nagar is insufficient. Hence, semi circular ring metro link has been proposed, it also provides connectivity to Sirpur, Bank, Ahirkhedi, Sukhniwas and Kodiabardi villages along with vital landuses i.e. Central Advance Technology, Regional Park and surrounded residential areas. Considering the future need, one more line is proposed towards south-eastern part covering important PSP hub. Bicholi Mardan and Bicholi Hapsi villages will also be benefited. Furthermore, this connectivity provides economic transport to villagers along the east ring road-3. In the central area of the city, line connecting collectorate office to line 4 via Juni Indore covering 1.3 km distance is not viable. Because, the minimum travel distance considered in the study is 1 km to reach the nearest metro station. Dewas city is the nearest industrial hub at a distance of approx 25km from terminating point of line 4 metro station. Extension of this line up to Dewas will provide faster mode of transport to industrial workforce migrating from Indore & Dewas and help to reduce traffic load on surface transport. Ward wise feasibility reveals that, 49 percent wards are directly connected and provide metro connectivity, whereas 51 % of the wards are dependent on their surrounding ones to get metro facility. Ward wise feasibility analysis depicts that 45 percent wards are most feasible for metro services, whereas 29percent& 21percent are moderately & less feasible. 5percent wards are not feasible for metro uses.

The connectivity analysis to evaluate use of metro services to imperative landuse facilities depicts that 35 percent stations connecting all-important landuses within the surrounding wards, whereas 38 percent metro stations provides connectivity from urban fringe to CBD. There are 13 percent metro stations, where road transport is more feasible and attract travelers in contrast of metro services. It is also observed that, Metro requires 54 percent of private land acquisition within 500 m buffer, which is one of the most important social factors to bring metro on ground as underground line only covering 9.8 percent.

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