Measuring Intersection Density and Pedestrian Route Directness for Walking

By

Hanu Kumar Singh
Roll No. 203180007
ESED, IIT Bombay

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Chapter 1
Introduction

1.1 Importance of Connectivity and Walkability

Streets with grid-like (interconnecting) patterns offer better connectivity to various places than streets with cul de sacs (streets closed at one end). Better connectivity implies shorter travel distance, encouraging walking, cycling and increased use of public transit (Beale, 2012). A walkable neighbourhood impacts mobility, liveability, public health, and social justice (Ewing and Cervero, 2010). A study also found out that well-connected pedestrian-friendly streets promote increased social interaction, thereby increasing attachment and satisfaction in the neighbourhood (Abass and Tucker, 2021).

On the other hand, a disconnected road network not only isolates people but also "space and resource-hungry patterns" (Gray, 2020). Low-density isolated neighbourhood forces dependence on automobile due to increased travel distance, resulting in increased congestion and traffic pollution. Moreover, travel comes with a cost either in terms of money or time. Therefore greater the travel, the greater is the cost involved. Figure 1 compares the 1-mile connectivity in a compact interconnected grid layout to a street network with cul de sacs in urban sprawl.

Figure 1.1 One mile connectivity in a grid layout and in a street network with cul de sacs (Source: Walk Score, 2021)

It can be observed that the grid layout offers better connectivity to various services than the street layout with cul de sacs. Therefore, a good street design is an important factor for good neighbourhood design.

1.2 Measure of Connectivity

The whole purpose of the transportation network is to connect people with places they want to visit. There is always a purpose associated with travel. Whether it is going to the office for work or visiting a park for recreation, there is always a purpose that creates a demand for travel. People do not travel merely because they enjoy travelling. Therefore, travel is considered a "derived demand" (Dill, 2004). It can be said that streets with good connectivity are, to a certain extent, walkable streets.

So to assess how good the connectivity of the street layout is, various quantitative measures have been proposed in the literature over the years (Ewing and Cervero, 2010). Here, two important network connectivity measures – intersection density and pedestrian route directness are studied.

The intersection density is defined as the number of road intersections per unit area (e.g. intersections per sq. km). It is a good proxy indicator to measure the connectivity as the higher the density, the greater is the connectivity (Dill, 2004).

Pedestrian Route Directness (PRD) is the ratio of the route distance to the direct distance between points. The lowest value is 1, and a higher PRD between two points means higher route distance implying poor connectivity between the points (Dill, 2004).

1.3 The objective of the paper

There has been hardly any study done to analyse the impacts of built form on people's travel patterns, especially in Indian cities. Since urbanisation is occurring rapidly, there is much opportunity for development in existing and new land parcels. Good connectivity walkable streets result in sustained urban development. The objective of the paper is to measure the connectivity of the streets of Mumbai ward wise using intersection density and PRD. Further, it looks at the correlation between these two measures of network connectivity.

Chapter 2 looks at the literature review, following which chapter 3 describes the methodology followed, chapter 4 looks at the results obtained, and finally, the conclusion is stated in chapter 5.

Chapter 2
Literature Review

2.1 Intersection Density

Figure 2.1 shows three street layouts – highly walkable street, moderately walkable street and low walkable street with the intersection density. All the street layouts are on the same scale.

Figure 2.1 Street layout of different cities with intersection density (Source: Jacobs, 1993)

Low intersection density corresponds to low connectivity, making it difficult to walk to places. In a meta-analysis study of various literature based on the impacts of the built environment on travel, Ewing and Cervero (2010) concluded that the intersection density of a street network had the highest impact on walkability. They estimated the elasticity of walking, vehicle miles travelled, and transit use with various built environment measurements (intersection density being one of the built environment measurements). They defined elasticity as "the ratio of the percentage change in one variable associated with the percentage change in another variable" (Ewing and Cervero, 2010, p. 272). For walking, intersection density showed the highest elasticity of 0.39 out of all the other built environment measures. This implies that if the intersection density increased by 100%, walking will increase by 39%. Therefore, intersection density is a good proxy indicator for the measurement of walkability. However, the authors also mention some limitations in their approach.

- The elasticities obtained are only ballpark estimates as the sample size is small and due to the approach used to estimate the elasticities.
- Considering the nature of the study, the authors could not put forth statistical confidence for the results obtained.
- The analysis was done based on the literature obtained before 2009.

2.2 Pedestrian Route Directness

Pedestrian Route Directness is another good indicator for measuring walking. People tend to walk considering the distance they have to walk, i.e. if the distance to a place is long, then people tend to avoid walking. Therefore, the distance to travel has a significant impact on whether a person would walk or use other modes of transport, and the PRD is a direct reflection of that (Dill, 2004). Figure 2.2 shows two street layout of the Portland Metro Area.

The street network on the left has a higher PRD than the street network on the right, indicating that the street network on the left has poor connectivity, whereas that on the roght has good connectivity since the value is closer to 1.

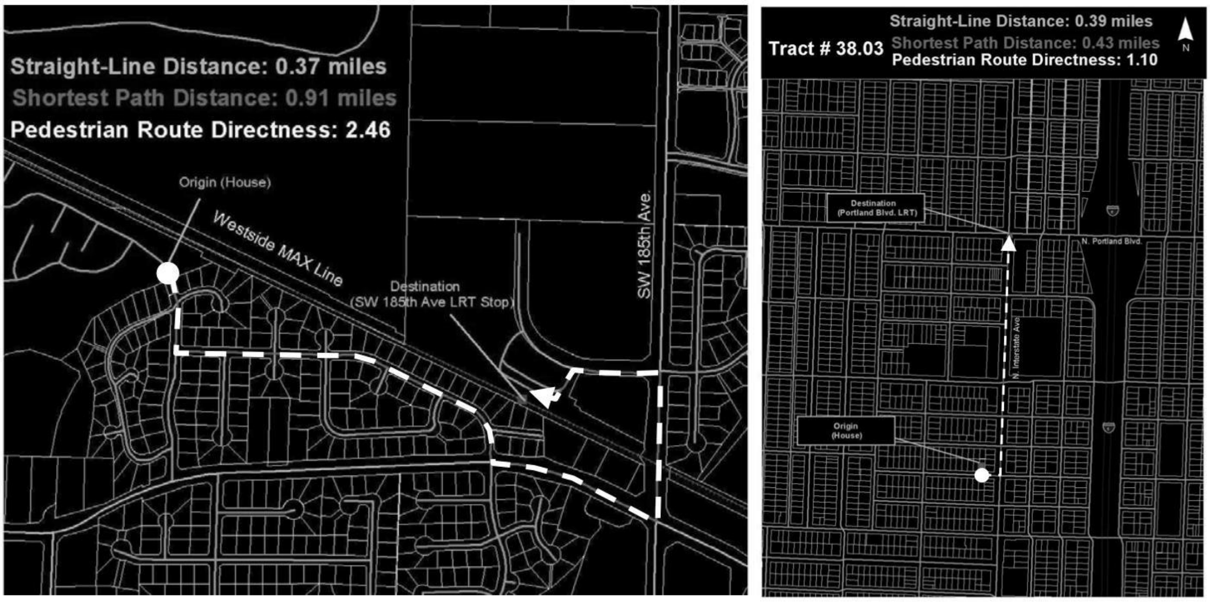

Figure 2.2 Pedestrian Route Directness for different street layouts of Portland Metro Area (Dill, 2004)

Although a good indicator for measuring walking, there are certain limitations too (Dill, 2004)

- PRD requires selecting two points, which may be subjective to the researcher and add to the computational complexity. Therefore, this method has not been used much for research and analysis involving many units of analysis
- It is not a good indicator for policy suggestions and decision making for planners.

Chapter 3
Materials and Methods

3.1 Study Area

The area selected is Greater Mumbai. The details of the city are as shown in Table 3.1.

Table 3.1 Details of Mumbai (Source: MCGM, 2016)

Latitude	19°4'22.19"N
Longitude	72°52'57.4"E
Administrative Body	Municipal Corporation of Greater Mumbai (MCGM), also known as Brihanmumbai Municipal Corporation (BMC)
Area	458.28 sq. km
Population	12.44 million (census 2011)
Population density	27,160 people/sq. km
Number of wards	24
Mode share of walk	51%
Daily trips by suburban rail	7 million
Daily trips by the bus transport system	5.5 million
Literacy rate	89.2% (city) and 89.9% (suburban)

The administrative boundary of the city with ward boundaries is shown in Figure 3.1.

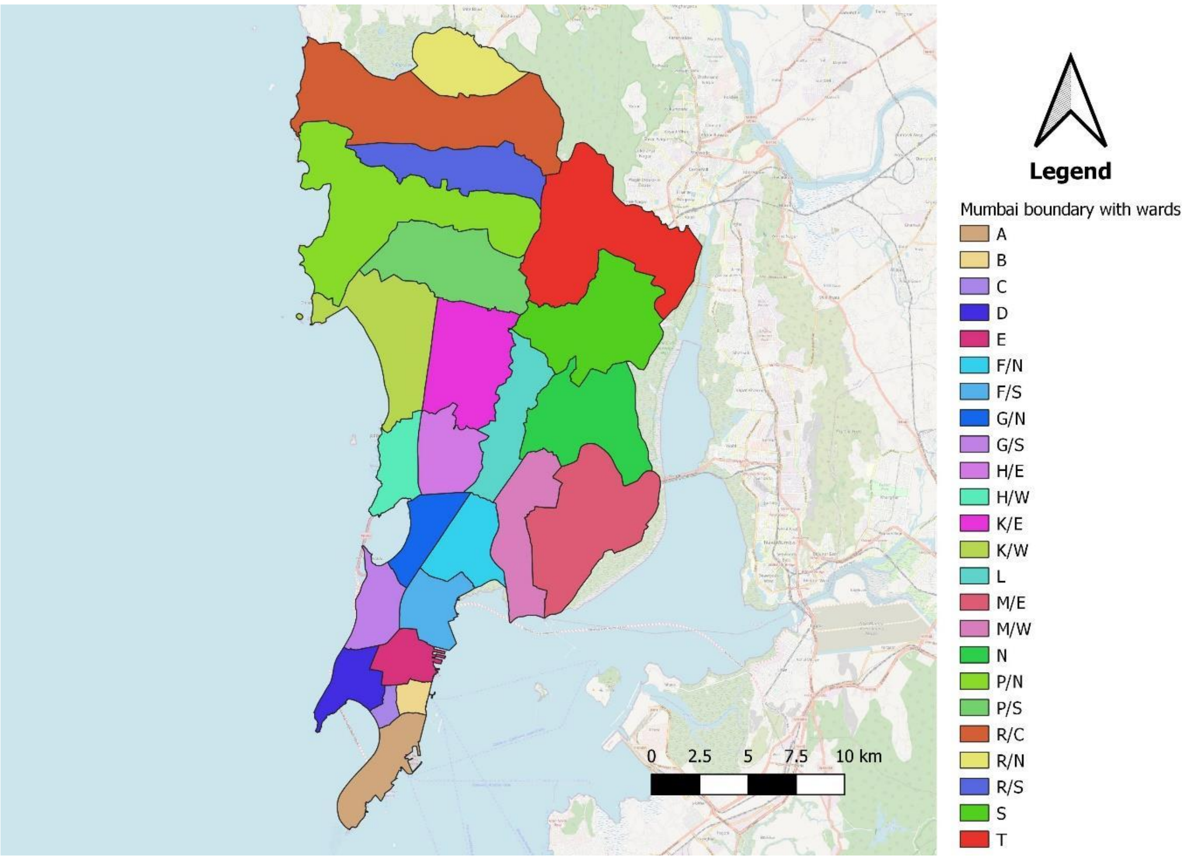

Figure 3.1 Mumbai ward boundaries

3.2 Data sources and tools

The list of data and the sources are shown in Table 3.2.

Table 3.2 Data and sources

Data	Source
Road Network data	Urban Road Network data from Figshare https://figshare.com/articles/dataset/Urban_Road_Network_Data/2061897
Ward Map data	Mumbai Spatial data from Github https://github.com/datameet/Municipal_Spatial_Data/tree/master/Mumbai

QGIS 3.18 software was used for mapping and spatial analysis, and Excel was used for calculation and data analysis.

3.3 Methodology

The step by step process involved in the creation of intersection density and PRD is as follows.

3.3.1 Creation of Intersection Density Map

Figure 3.2 shows the initial road network of the Mumbai Metropolitan Region (vector data) and the Mumbai ward boundary (vector data) that was added in the QGIS.

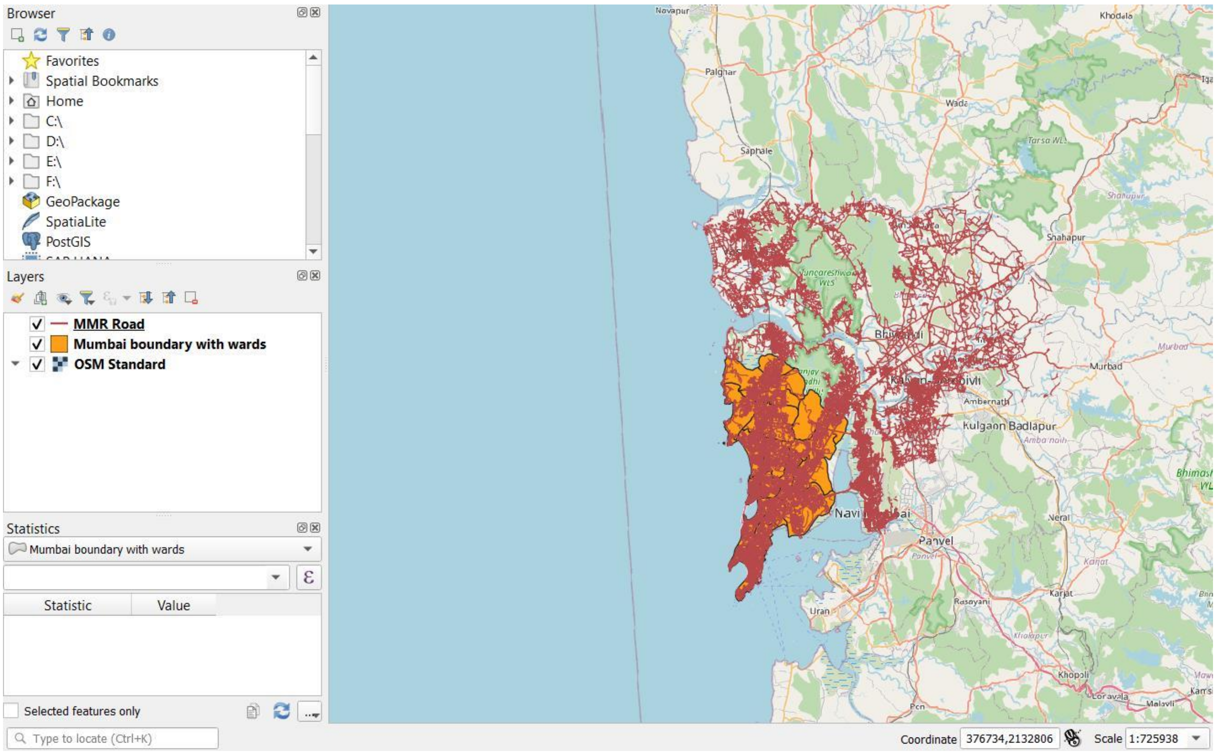

Figure 3.2 Mumbai Metropolitan Region (MMR) road network and ward boundary data

The road layer was clipped using the clip tool to obtain the road network for Greater Mumbai region only. The input layer was the "MMR road", and the overlay layer was the "Mumbai boundary with wards" layer. The road network obtained after clipping is as shown in Figure 3.3. The new layer obtained after the clipping was named "Mumbai Road Network".

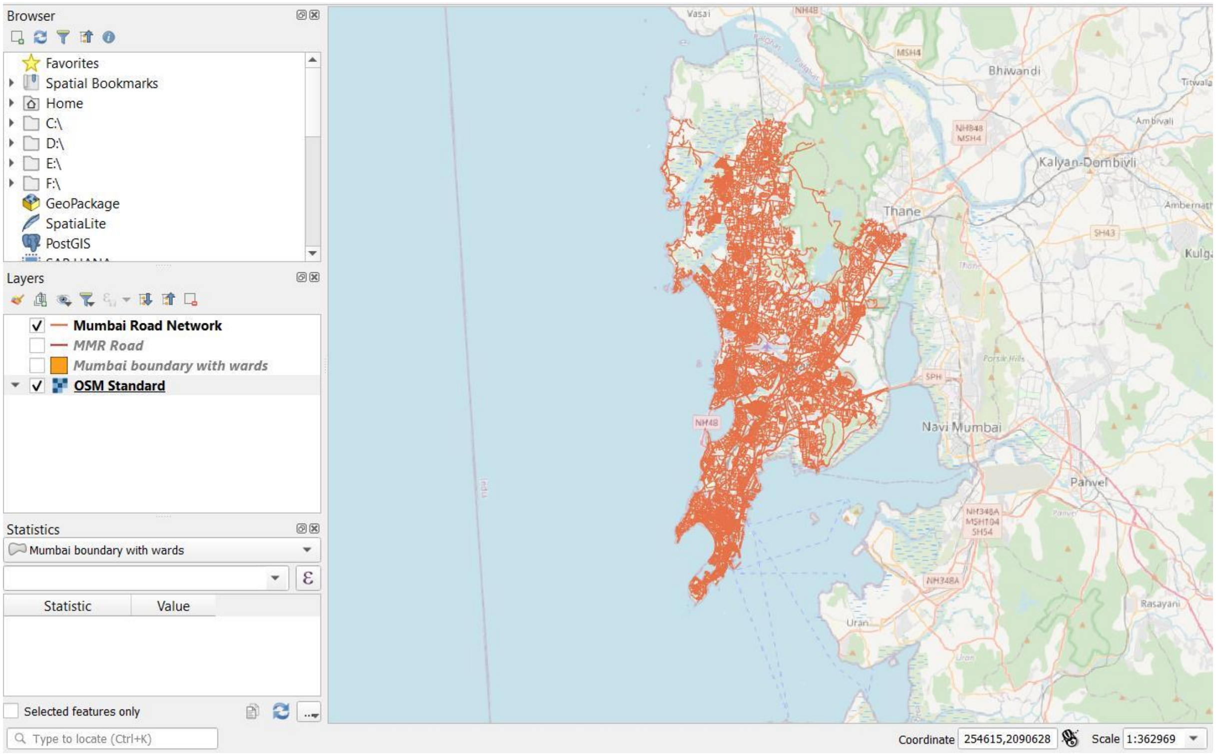

Figure 3.3 Mumbai Road Network layer obtained after clipping

The road network obtained, however, had different lines indicating the lanes of the road. These extra lines were redundant, and it would indicate way higher intersection points than it is and give false output. Therefore, these extra lines had to be removed manually, which was a very time consuming and rigorous task. Figure 3.4 shows the before and after deleting the redundant lines of various locations in Mumbai.

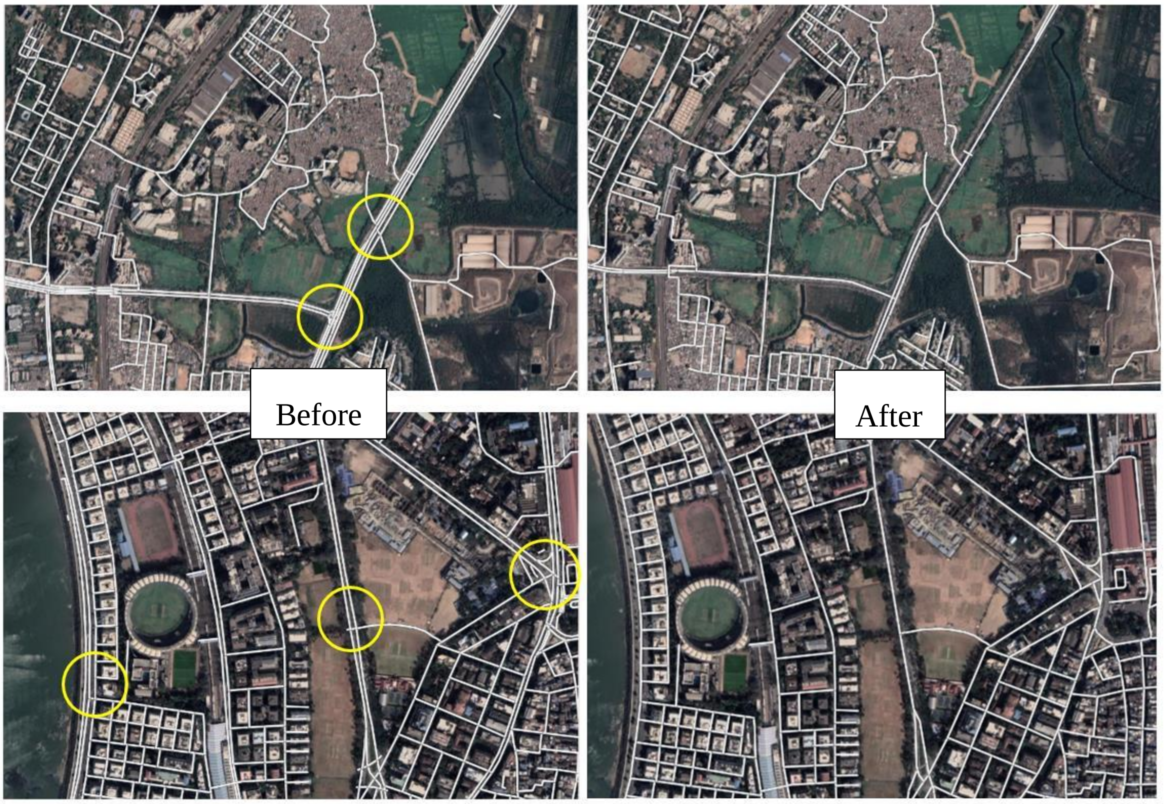

Figure 3.4 Before and after deleting the redundant lines. Yellow circle indicate extra intersection points that would be created as a result of redundant lines.

Finally, after days of clearing all the redundant lines, it was checked for any duplicate geometries. The cleaned road layer was named "Mumbai Road (Cleaned)". To obtain the intersection points, a line intersection tool was used. Here both the input and the intersect layer were the same, i.e. "Mumbai Road (Cleaned)" layer. About 119,562 intersection points were generated. Again this new layer was checked for duplicate geometries. The layer generated as a result was named "Intersections (Cleaned)" and had 18,713 intersection points. Figure 3.5 shows the intersection points generated.

Figure 3.5 Intersection points

To calculate the intersection density (points/sq. km), the number of intersections was estimated for each ward. For this, Count Points in Polygon tool was used. The polygon was the "Mumbai boundary with wards" layer, and the points were the "Intersections (Cleaned)" layer. The output had the attributes of both the layers. The new layer generated was named as "Intersection Count" layer. Two new fields were added in this layer – Area (sq. km) and Intersection Density (points/sq. km). The expression used for the two fields is as follows.

$$\text{Area (sq. km)} = \text{area (sq. m)}/1000000$$

$$\text{Intersection Density } \left(\frac{\text{points}}{\text{sq. km}}\right) = \frac{\text{NUMPOINTS}}{\text{Area (sq. km)}}$$

Figure 3.6 shows the attribute table of "Intersection Count", and Figure 3.7 shows the maps of intersection density (points/sq. km) ward wise.

Count — Features Total: 24, Filtered: 24, Selected: 0

	gid	name	NUMPOINTS	Area (sq, m)	Area (sq. km)	Intersection Density (points/sq. km)
1	1	A	1508	11203540	11	137
2	2	B	400	2656945	3	133
3	3	C	384	1912081	2	192
4	4	D	939	8219196	8	117
5	5	E	701	7270370	7	100
6	8	F/N	638	12278150	12	53
7	6	F/S	429	9783366	10	43
8	9	G/N	2158	8760008	9	240
9	7	G/S	415	9289113	9	46
10	18	H/E	548	12413561	12	46
11	23	H/W	661	9024750	9	73
12	19	K/E	827	23953255	24	34
13	14	K/W	1155	24540769	25	46
14	24	L	706	15674792	16	44
15	16	M/E	694	33069941	33	21
16	17	M/W	617	17396398	17	36
17	10	N	659	25680044	26	25
18	21	P/N	1088	46693778	47	23
19	20	P/S	696	25179528	25	28
20	11	R/C	1429	48006765	48	30
21	15	R/N	243	14172421	14	17
22	22	R/S	799	18304826	18	44
23	12	S	647	29741187	30	22
24	13	T	372	42859407	43	9

Show All Features

Figure 3.6 Attribute Table of Intersection Count layer

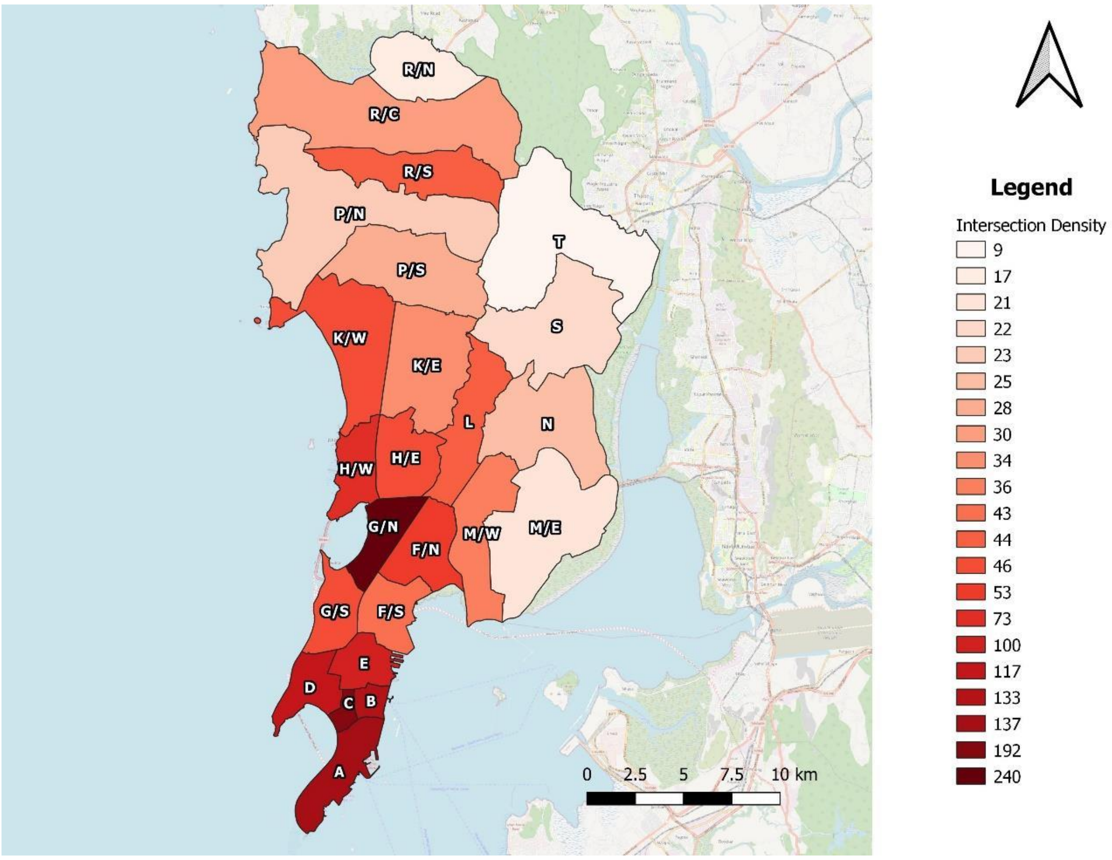

Figure 3.7 Ward wise intersection density

3.3.2 Estimating Pedestrian Route Directness

To estimate the PRD in different wards of Mumbai, as mentioned before, two points are to be marked. Here a pair of points were selected for each ward such that one of the point (point A) is a transit station (suburban or metro), and the other is an important place of visit (point B) like school, college, hospital, office etc. that is near to the station. Here, a transit station was chosen as it has been observed that the streets around transit stations are usually well connected, and to maintain a uniform standard in the selection of points, point A was selected as a transit station. Figure 3.8 shows the point A and B marked for each ward for PRD.

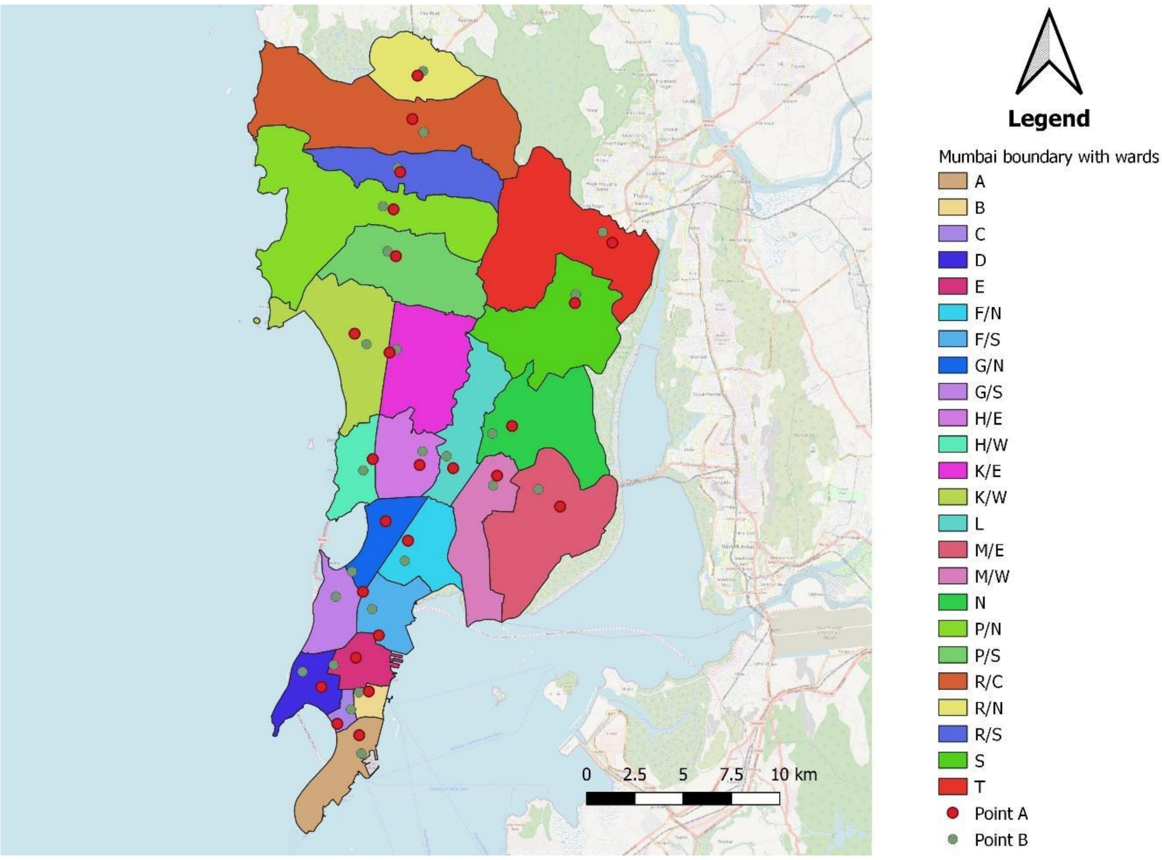

Figure 3.8 Points A and B for different wards of Mumbai for measuring PRD

After marking the points A and B for each ward, the PRD was calculated, which is estimated as follows

$$PRD = \frac{Shortest\ Path\ Distance}{Straight\ Line\ Distance}$$

The shortest path distance was calculated for the pair of point for each ward using network analysis, and the straight line distance between the points was calculated using the measure line tool. Figure 3.9 shows the shortest path estimate of each ward using QGIS.


A
B
C
G/N
E
D
F/S
F/N
G/S
H/E
H/W
K/E
L
K/W
M/E
M/W
N
P/S
P/N

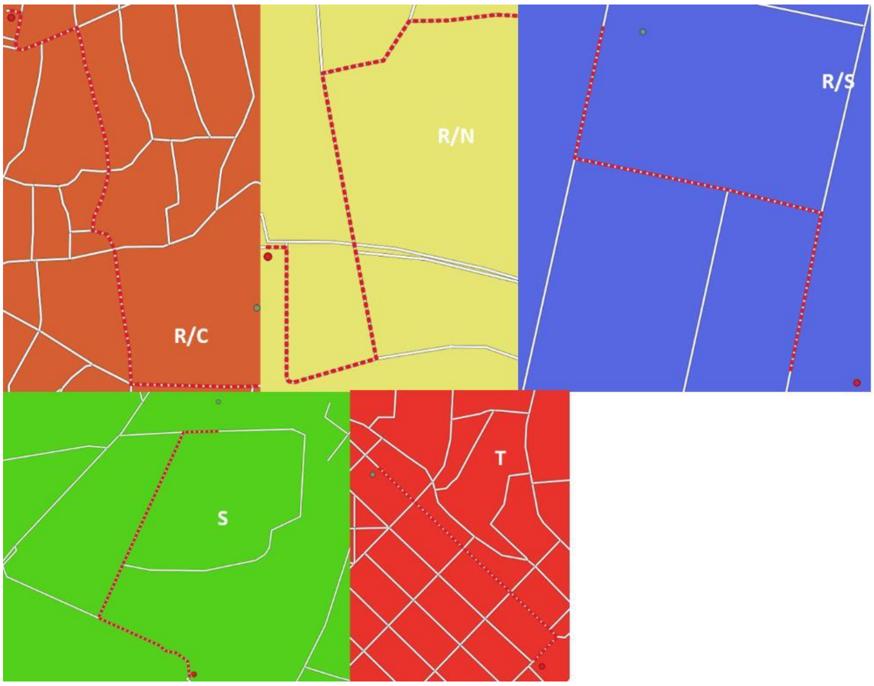

Figure 3.9 Shortest path distance between the points in all 24 wards of Mumbai

Following this, a table was prepared in Excel, and the PRD was calculated. Table 3.3 shows PRD values.

Table 3.3 Calculation of Pedestrian Route Directness for different wards of Mumbai

Ward	**Point A**	**Point B**	**Shortest Path Distance (m)**	**Straight Line Distance (m)**	**Pedestrian Route Directness**
A	CSMT Station	Asiatic Library	1134.385	954.551	1.188
B	Sandhurst Road Station	Jmamiya Masjid	722.775	522.985	1.382
C	Marine Lines Station	Shree Mumbadevi Temple	1503.890	1027.225	1.464
D	Grant Road Station	Sophia College	2069.203	1254.681	1.649
E	Byculla Station	Nair hospital	1579.407	1208.212	1.307
F/N	Kings Circle Station	VJTI	1185.659	1055.194	1.124
F/S	Cotton Green Station	Global Super Speciality Hospital	2494.643	1401.555	1.780
G/N	Mahim Junction Station	Siddhivinayak Mandir	3619.395	3136.347	1.154
G/S	Prabhadevi Station	Reliance Life Sciences Pvt. Ltd.	1903.538	1430.754	1.330
H/E	Mumbai BKC Metro Station	Golden Square Park	2233.416	719.139	3.106
H/W	Khar Road Station	R D National College	1001.211	765.121	1.309
K/E	Andheri Station	Shri Chinal College of Commerce and Economics	591.666	401.534	1.474
K/W	D.N. Nagar Station	SPCE	1600.134	824.691	1.940
L	Kurla Station	Equinox Business Park	934.576	703.607	1.328
M/E	Mankhurd Station	M/E Ward Office	2228.889	1436.741	1.551
M/W	Chembur Station	Gandhi Maidan	706.991	551.935	1.281
N	Ghatkopar Station	Fatima High School	1200.617	1098.383	1.093
P/N	Malad Station	Abhijit Hospital	781.380	565.647	1.381
P/S	Goregaon Station	Podar College of Science	770.395	506.056	1.522
R/C	Borivali Station	Oberoi Sky City	1454.846	895.589	1.624
R/N	Dahisar Station	Life Care Hospital	831.836	375.027	2.218
R/S	Kandivali Station	Kandivali Fire Station	343.594	256.170	1.341
S	Bhandup Station	Pawar Public School	603.091	458.020	1.317
T	Mulund Station	Mulund Police Station	808.918	745.433	1.085

Based on the values of PRD, a map of ward wise PRD was prepared, as shown in Figure 3.10. It is to be noted that a higher value of PRD indicates poor walkability.

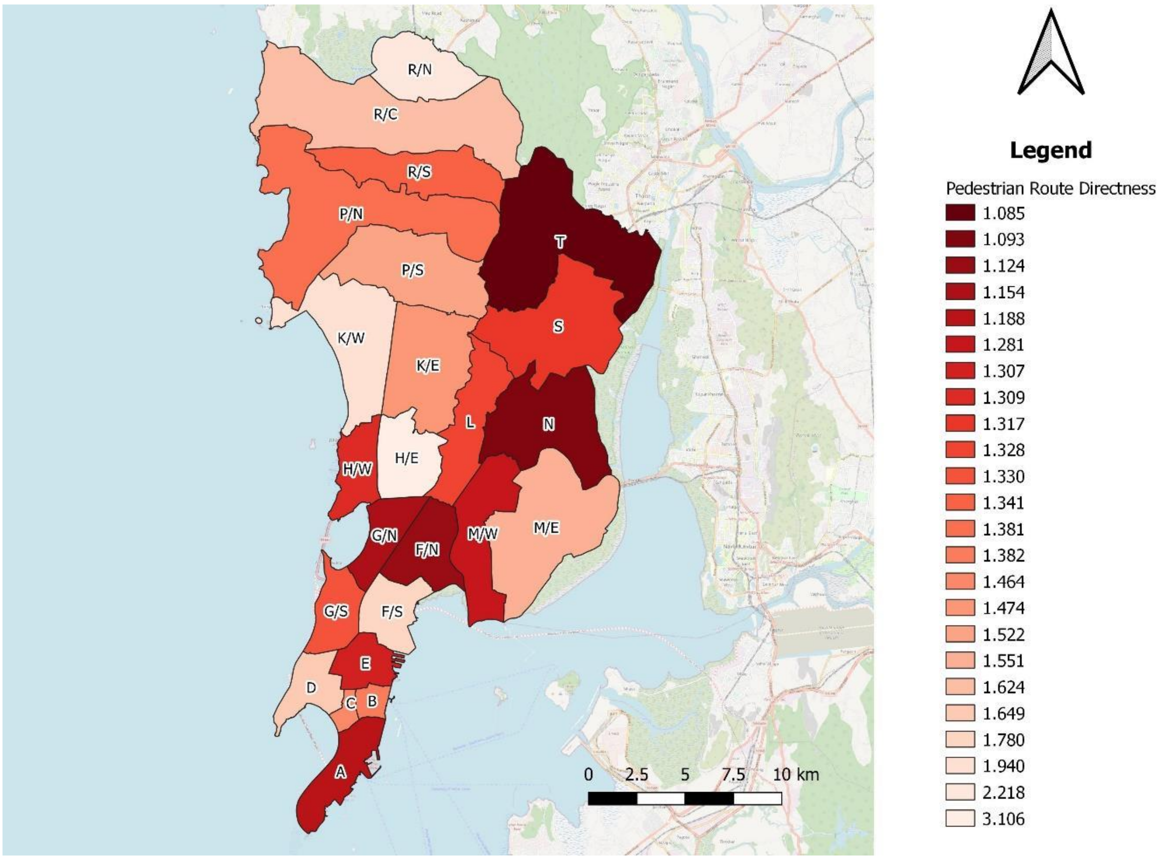

Figure 3.10 Ward wise Pedestrian Route Directness

Chapter 4

Results and Discussions

The final maps obtained after the calculation of intersection density and PRD are as shown in Figure 4.1.

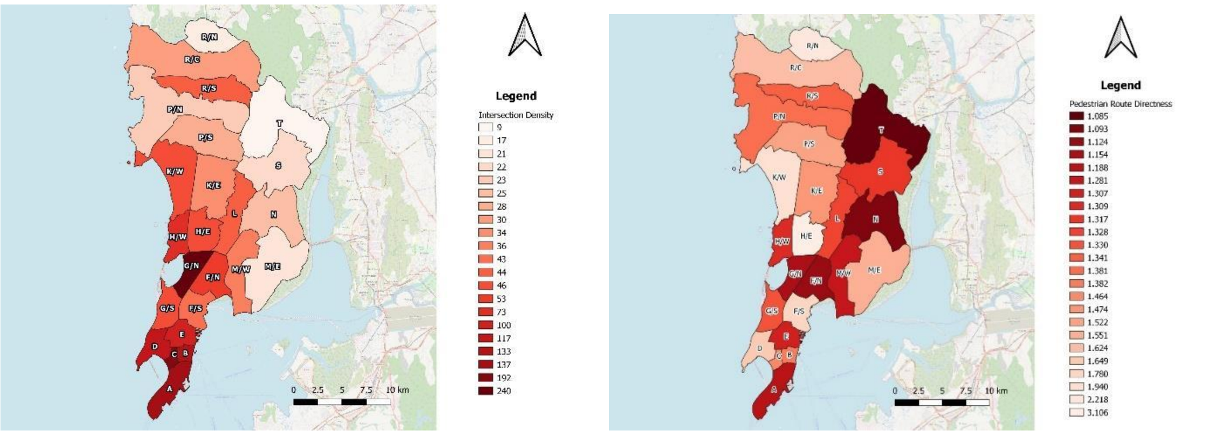

Figure 4.1 Comparison of intersection density and PRD maps

Table 4.1 shows the descriptive statistics of the two connectivity measures (n = 24).

Table 4.1 Descriptive statistics of connectivity measures

	Intersection Density (points/sq. km)	**Pedestrian Route Directness**
Sum	1559	35.95
Mean	64.96	1.50
Median	44	1.36
Standard Deviation	59.02	0.44
Minimum	9	1.08
Maximum	240	3.11
Range	231	2.03

Although the intersection density and the PRD are measuring two different things, both are considered proxy indicators of walkability and therefore, it would be interesting to check their correlation.

Using Pearson's Correlation, the correlation between intersection density and PRD was found out to be – 0.184. Ideally, a positive correlation should have been observed as higher intersections imply higher connectivity and higher walkability. However, it is still not surprising to see a negative correlation as certain ambiguity is associated with these connectivity measures. For instance, it can be observed that the PRD is very good for the T ward as it is close to 1 due to the interconnected grid layout. However, the intersection density is low as a major portion of the ward is under Sanjay Gandhi National Park, a reserved forest and has a small portion of the area with a road network. Here, the intersection density gives a false idea of low walkability in the T ward due to its large area.

Similarly, comparing the two maps in Figure 4.1, it can be understood that there is a stark difference in the way these two measures tell us about the walkability in the district. Although PRD is an excellent measure of determining the walkability of a small neighbourhood, for large areas like ward, where there are almost endless combinations of choosing a pair, the PRD measure is not very reliable as choosing points become subjective to the researcher.

The spatial data from the intersection density indicates that the core city with dense urban development has way higher intersections and, therefore, good connectivity compared to the suburban sprawls where the intersection density is low with the exception of the R/S ward. The intersection density showed an extensive range with a minimum value of 9 to a maximum value of 240.

Finally, comparing the two maps, it can also be said that most of the wards in the core city showed a positive correlation between the intersection density and the PRD; however, the same cannot be said as we go north towards the suburbs. A reason for this could be that the road network takes up the entire area in the core city, which is not the case in the suburbs, where roads cover only a portion of the area.

Chapter 5
Conclusion

Studying connectivity measures is an important aspect for determining a good built environment for a city. The built environment affects the people's travel demand and mode share. Cities in developing countries are undergoing urbanisation at a rapid pace, and therefore it is of utmost importance to study the impacts of the built environment.

This paper looked at the two important connectivity measures – the intersection density and the pedestrian route directness for different wards of Mumbai. The spatial analysis provided an interesting finding that even though both of them are measures of connectivity, it does not mean both the parameters are correlated to one another. Moreover, it was understood that although these measures give a rough idea about connectivity and walkability, there are certain ambiguities associated with these measures, and one cannot simply conclude whether an area or a neighbourhood has good connectivity based on only one measure of connectivity. Apart from these two, one can also look at other measures of connectivity and look at how the demographics of a place impact the mode choice.

To conclude, there is no best approach for measuring walkability as it cannot be quantified. All these quantitative measures only provide a rough estimate, and the effectiveness of these methods are highly contextual. Nevertheless, these are powerful methods as it helps planners in creating cities with good neighbourhoods.

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