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Influence of pedestrian movement on speed of vehicles, capacity and level of service of urban midblock sections

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Abstract

Side friction factors are all those actions related to the activities taking place by the sides of the road and sometimes within the road, which interfere with the traffic flow on the travelled way. They include but not limited to pedestrians, bicycles, non-motorized vehicles, parked and stopping vehicles. These factors are normally very frequent in densely populated areas in developing countries, while they are random and sparse in developed countries making it of less interest for research and consequently there is comparatively little literature about them. The objective of this thesis is to analyze the effect of these factors on capacity of urban roads. The present study is mainly focused on individual effect of the friction factors like pedestrians crossing the road on capacity of urban roads. Data on two sections of 4-lane divided road were collected in Hyderabad with pedestrian cross flow. These are taken as the base sections. Three basic parameters of traffic speed, volume and density are used for estimation of traffic carrying capacity of a road. For determination of speed-volume relationship in heterogeneous traffic condition, the volume calculated by total vehicles recorded for each counting period were converted into equivalent number of PCUs. Mean stream speed or weighted space mean speed is calculated and used in the present study. The present study demonstrates that mix traffic stream can be converted in to an homogeneous equivalent of passenger cars by multiplying the total traffic volume (in veh/hr) by a stream equivalency factor (K). It will avoid the problem of estimation of PCU values for individual vehicle categories in the traffic stream. The stream equivalency factor (K) will depend on traffic composition and a regression equation is developed in this study to estimate K-value on urban roads.

Keywords: Side friction factors; Capacity; Pedestrians; Urban roads

1. Introduction

Urban areas in most of the developing countries are facing major challenges in traffic management and control and India is no exception. It has witnessed a rapid growth in economy in recent years, resulting in vehicle ownership levels growing at a faster rate. The total road length in India including highways, rural roads, urban roads, project roads as on 31s` March 2008 was 42,3 6,429 km. The total length of urban roads in the country as on 31st March 2004 was 3,01,3 10 km which increased to 3,04,327 km by March 2008 (MORT&H, 2010) indicating a growth of about 1 percent. Capacity analysis is fundamental to planning, design and operation of roads. Among other things, it provides the basis for determining the number of traffic lanes to be provided for different road sections having regard to volume, composition, and other parameters of traffic. Alternatively, for existing road network, the capacity analysis provides a means of assessing the traffic carrying ability of the number of traffic lanes provided for a given road link under the prevailing roadway and traffic conditions. Capacity standards can therefore help in rational evaluation of the investments needed for further road construction and improvements.

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Indian urban roads are typically categorized with the mixed nature of traffic. Mixed traffic represents the conglomeration of different vehicles those having much variation in their operating speeds, fleet size and difference in maneuvering abilities. Speed varies from 3.5 km/hr in case of hand carts to 60 km/hr or more for passenger cars. Presence of slow-moving vehicles in traffic stream results in reduced average speed of the traffic stream. Consequently, this speed reduction results in frequent stoppages, acceleration and deceleration and movement in lower gear increases the operational cost exorbitantly besides giving rise in environmental pollution. The conflict, confusion and the irritation caused by mixed traffic with lane indiscipline result in a large number of accidents. This leads to frequent congestion on urban roads.

2. Data extraction

The video recorded data were used to extract the information on classified traffic volume count and speed of individual vehicles. All vehicles are divided in to 4 categories and their average physical dimensions are shown in Table-3.2.

Table 1 Vehicle Categories and their Average Dimensions

S.NO	Class of vehicle	Average dimensions		Projected rectangular plan area (m^2)
		Length(m)	Width(m)	
1	Standard car	3.72	1.44	5.39
2	Bus/truck	10.10	2.43	24.74
3	Three-wheeler	3.20	1.4	4.48
4	Two-wheeler	1.87	0.64	1.2

The standard car is taken as a passenger car having length 3.98 m, width 1.54 m and engine power of 1405 cc. Tata Indigo, Indica, Hyundai Getz etc. were considered as standard cars. The classified volume count of all vehicles passing through a specified point, say first line of the trap, during a fixed period of 5 minute provided the measurement for composition and flow. The average time taken by each category of vehicle to cover the trap length was recorded using a digital stop watch of 0.01 second accuracy. The precaution was taken to consider only those periods during which there was continuous flow of the vehicles with representation of each category. For the purpose of speed measurement of a vehicle type, 6-8 vehicles of that category were randomly picked up during the flow and average of speeds was taken for the analysis.

3. Analysis of data and result

The data on classified volume count and average speed of each vehicle category on the selected mid-block were extracted from the video film in the manner. The data were analyzed to obtain the average speed of the vehicles on traffic stream, hourly traffic volume and speed (m/s) of each type of vehicle on different mid-block sections. From the video films obtained, the speed of individual vehicles in the normal traffic flow and the classified volume was estimated for `of the vehicles on traffic stream at different sections is given in Table.

Table 2 Speed Analysis Of Vehicles At Medchal Location

TIME	2W SPEED	3W SPEED	4W SPEED	HV SPEED	PEDESTRAIN COUNT	2W FLOW	3W FLOW	4W FLOW	HV FLOW
8:30-8:35	7.138	5.282	4.013	3.730	53	131	33	70	28
8:35-8:40	9.759	7.939	3.825	3.607	55	142	22	87	27
8:40-8:45	7.424	7.091	5.511	4.538	59	135	19	53	23
8:45-8:50	8.405	6.753	4.852	4.564	44	123	21	47	21
8:50-8:55	7.383	5.590	4.498	3.393	51	122	25	77	22
8:55-9:00	8.106	6.194	4.421	3.555	42	123	21	52	23

9:00-9:05	7.500	5.119	3.413	3.437	68	114	18	71	19
9:05-9:10	7.488	4.789	3.138	2.849	68	130	19	80	39
9:10-9:15	7.247	6.016	4.058	3.295	57	112	30	81	30
9:15-9:20	6.126	5.0283	4.974	4.003	66	115	23	80	36
9:20-9:25	6.113	4.592	3.092	2.384	69	113	23	62	32
9:25-9:30	6.316	4.594	3.812	3.332	66	146	25	96	30
9:30-9:35	8.025	6.929	4.539	3.116	37	145	32	85	35
9:35-9:40	5.951	3.753	2.928	2.129	82	124	22	93	37
9:40-9:45	7.116	5.210	3.313	3.446	52	137	25	63	27
9:45-9:50	8.958	6.746	3.462	3.287	36	118	18	86	29
9:55-10:00	7.039	5.269	4.205	3.905	47	152	22	83	25
10:00-10:05	7.359	6.357	4.099	3.369	42	143	16	95	23
10:05-10:10	8.234	4.949	3.901	3.226	38	140	26	92	19
10:10-10:15	9.916	7.282	6.886	5.862	29	154	34	94	18
10:15-10:20	8.950	6.729	3.514	3.509	42	142	29	86	19
10:20-10:25	9.453	8.763	5.948	4.014	32	113	18	97	20
10:25-10:30	10.043	8.636	7.806	5.158	28	133	20	74	17
4:00-4:05	12.961	10.198	5.365	5.866	19	105	23	84	29
4:05-4:10	12.226	10.580	6.359	4.076	24	89	22	54	28
4:10-4:15	6.822	5.808	4.148	3.729	56	100	21	49	26
4:15-4:20	7.099	5.56	3.105	2.127	66	111	16	71	27
4:20-4:25	8.535	4.596	3.522	3.440	59	80	20	59	37
4:25-4:30	7.549	4.041	3.828	3.906	47	120	25	56	19
4:30-4:35	7.106	3.975	3.370	3.446	48	100	21	67	32
4:35-4:40	6.906	3.694	3.186	3.573	67	104	29	65	30
4:40-4:45	9.347	3.371	2.478	2.332	63	98	19	74	28
4:45-4:50	6.299	5.433	3.480	2.057	65	116	25	68	27
4:50-4:55	7.402	6.205	4.821	3.811	53	90	26	46	21
4:55-5:00	6.428	5.356	4.350	3.257	56	111	22	69	28
5:00-5:05	7.900	4.689	3.493	3.145	68	115	19	51	25
5:10-5:15	6.884	4.756	3.335	2.755	69	124	30	62	30
5:15-5:20	7.276	7.004	3.445	3.623	56	112	14	53	24
5:25-5:30	12.717	10.238	5.456	4.895	24	95	15	64	27
5:30-5:35	8.102	6.526	4.956	4.079	35	99	24	36	16
5:35-5:40	8.161	6.565	4.188	4.023	39	117	21	55	25
5:40-5:45	7.732	4.351	3.578	3.753	50	103	21	73	37
5:45-5:50	8.576	5.360	3.797	3.664	41	110	16	61	33
5:50-5:55	8.984	6.466	5.412	4.581	34	112	17	87	28

5:55-6:00	8.254	4.935	3.187	3.147	36	141	31	64	25
3:00-3:05	16.297	11.149	9.986	8.191	15	87	12	68	31
3:05-3:10	14.783	12.362	10.256	8.640	10	91	12	76	32
3:10-3:15	15.027	10.734	10.564	8.185	19	89	23	58	39
3:15-3:20	15.99	13.144	10.178	9.396	16	94	14	70	34
3:20-3:25	13.386	11.107	9.215	8.210	26	89	15	57	32
3:25-3:30	13.4	11.668	9.197	8.239	21	113	13	81	25
3:30-3:35	14.132	10.343	9.106	8.490	21	89	14	71	33
3:35-3:40	15.371	10.520	9.313	7.924	25	118	20	52	29
3:40-3:45	14.065	11.150	9.523	9.302	26	95	13	69	30
3:45-3:50	15.135	12.442	9.239	6.161	54	98	16	75	23
3:50-3:55	14.492	11.344	9.469	8.199	36	119	23	68	33
3:55-4:00	15.288	9.857	9.442	7.887	40	107	18	61	19
4:00-4:05	14.369	9.631	8.459	5.802	51	130	26	66	16
4:05-4:10	14.313	10.276	9.610	7.595	27	79	17	58	20
4:10-4:15	15.511	10.078	9.856	8.448	17	82	13	47	23
4:15-4:20	15.372	10.101	8.767	7.715	23	134	15	88	44
4:20-4:25	13.968	10.286	8.707	8.201	34	130	21	95	36
4:25-4:30	13.257	9.423	9.043	8.157	21	108	23	69	37
4:30-4:35	13.569	9.281	8.828	7.654	33	118	19	87	30
4:35-4:40	13.351	9.938	8.520	7.101	18	107	14	83	31
4:40-4:45	13.555	10.271	8.480	9.009	23	109	18	71	28
4:45-4:50	14.057	10.767	9.287	7.131	18	121	18	66	32
4:50-4:55	14.627	11.823	8.751	7.398	24	100	13	87	24
4:55-5:00	14.676	10.663	8.816	8.664	31	142	17	91	30
5:00-5:05	12.796	11.433	9.171	8.601	39	116	17	60	21
5:05-5:10	13.714	10.433	8.963	6.478	25	142	19	97	20
5:10-5:15	14.15	9.669	9.212	5.615	30	126	15	84	37
5:15-5:20	14.881	9.897	8.785	7.357	20	72	22	70	32
5:20-5:25	14.553	11.727	8.668	6.492	25	113	21	79	34
5:25-5:30	14.522	10.538	8.313	7.114	31	129	23	81	26
5:30-5:35	13.406	11.301	8.649	6.627	20	135	24	80	29
5:35-5:40	14.525	10.433	9.559	5.685	36	124	16	88	22
5:40-5:45	13.882	10.158	9.832	5.648	28	157	22	82	23
5:45-5:50	14.133	11.156	9.180	4.871	63	159	20	71	34
5:50-5:55	13.28	11.266	9.221	5.511	38	171	16	76	24
5:55-6:00	13.674	11.139	8.294	5.856	52	137	21	89	29

3.1. Speed

Speed is considered as a quality measurement of travel as the drivers and passengers will be concerned more about the speed of the journey than the design aspects of the traffic. It is defined as the rate of motion in distance per unit of time. Mathematically speed or velocity v is given by

$$v = d/t$$

where, v is the speed of the vehicle in m/s, d is distance traveled in m in time t seconds. Speed of different vehicles will vary with respect to time and space. To represent these variation, several types of speed can be defined. Important among them are spot speed, running speed, journey speed, time mean speed and space mean speed.

3.2. Analysis of Vehicular Speeds

The average values for the free-flow speeds, speeds during peak hour traffic and operating speeds. Free-flow speed is an important characteristic which affects the capacity, service flow rate, service volumes and daily service volumes. Free-flow speeds were determined separately for the pedestrian cross flow and ideal location. It was seen that the average free flow speeds were almost similar for ideal and pedestrian cross flow location for the site at Medchal .

3.3. Speed prediction models

Multiple linear regression models were developed for individual as well as combined side friction parameters for speed prediction. Frictional parameters discussed in previous section were considered as the independent variable while the dependent variable chosen was the average speed (m/s) of the traffic flow.

$$[Y = a_0 + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + a_5x_5 + a_6x_6 + a_7x_7 + a_8x_8 \ldots\ldots\ldots a_nx_n]$$

For Speed of 2W:-

$$V_{2w} = 2.988 + 0.493x_{3w} + 0.561x_{4w} + 0.114x_{hv} - 0.010x_{ped} - 0.009x_{2w\text{-}flw} - 0.004x_{3w\text{-}flw} + 0.008x_{4w\text{-}flw} + 0.023x_{hv\text{-}flw} \qquad \mathbf{(R^2=0.91)}$$

(4.148) (3.366) (0.743) (0.975) (1.252) (0.149) (0.905) (1.140)

For Speed of 3W :-

$$V_{3w} = 2.508 + 0.390x_{2w} + 0.452x_{4w} - 0.071x_{hv} - 0.015x_{ped} - 0.009x_{2w\text{-}flw} - 0.004x_{3w\text{-}flw} + 0.008x_{4w\text{-}flw} + 0.023x_{hv\text{-}flW} \qquad \mathbf{(R^2=0.90)}$$

(4.148) (3.265) (-0.520) (-1.586) (0.937) (1.673) (0.125) (1.008)

For Speed of 4W :-

$$V_{4w} = -2.686 + 0.280x_{2w} + 0.285x_{3w} + 0.509x_{hv} + 0.009x_{ped} + 0.009x_{2w\text{-}flw} + 0.004x_{3w\text{-}flw} - 0.005x_{4w\text{-}flw} - 0.007x_{hv\text{-}flw} \qquad \mathbf{(R^2=0.93)}$$

(3.666) (3.265) (5.548) (1.152) (1.838) (0.239) (0.719) (0.506)

For Speed of HV :-

$$V_{HV} = 3.138 + 0.066x_{2w} - 0.052x_{3w} + 0.588x_{4w} - 0.023x_{ped} - 0.009x_{2w\text{-}flw} - 0.007x_{3w\text{-}flw} - 0.002x_{4w\text{-}flw} + 0.018x_{hv\text{-}flw} \qquad \mathbf{(R^2=0.88)}$$

(0.743) (0.520) (5.548) (2.901) (1.667) (0.366) (0.290) (1.163)

Where,

- y = dependent variable
- x values = independent variables
- Vped = speed (m/s) for pedestrian movement
- X_{2W} = Speed of 2 Wheelers in m/s
- X_{3w} = Speed of 3 Wheelers in m/s
- X_{4w} = Speed of 4 wheelers in m/s
- X_{hv} = Speed of heavy vehicles in m/s
- X_{ped} = Number of pedestrian movement in 5mins of interval
- $X_{2w\ Flow}$ = Number of 2 wheelers in 5mins of interval
- $X_{3w\ Flow}$ = Number of 3 wheelers in 5mins of interval
- $X_{4w\ Flow}$ = Number of 4 wheelers in 5mins of interval
- $X_{hv\ Flow}$ = Number of heavy vehicles in 5mins of interval

4. Capacity

Capacity of a transport facility is defined as the maximum number of vehicles, passengers, or the like, per unit time which can be accommodated under given conditions with a reasonable expectation of occurrence. The Highway Capacity Manual(2010) defines the capacity as the maximum howdy rate at which persons or vehicles can be reasonably expected to traverse a point or a uniform segment of a lane or roadway during a given time period, under prevailing roadway, traffic and control conditions. Several observations can be made from the above definition. Although capacity is the maximum howdy rate, in many situations the break 5 minute flow rate is expressed as the capacity. The above definition also contains the term “reasonably expected” to account for the variation in traffic and driving habit at various location. However, it can be termed as a probabilistic measure. Further, analytical derivations are possible for getting the maximum flow rate, seldom it is achieved in the field. However, capacity measures are often empirically derived. Capacity is usually defined for a point or a uniform segment where operating conditions do not vary. The capacity measure depends on these operating conditions. The first is the traffic conditions and the factors that influence the capacity includes vehicle composition, turning, movements, etc. The second factor is the roadway conditions and it includes geometrical characteristics such as lane width, shoulder width, horizontal alignment, vertical alignment. The third factor is the control conditions such as the traffic signal timings, round-about characteristics.

Table 3 Capacity and Recommended Design Service Volume of Base Section of Urban Roads

S.No	Typology of the Road	Capacity *(PCUs/hr)*	Lane Capacity *(PCUs/hr)*	Design Service Volume*(PCUs/hr)*
1	Two-Lane Undivided	2400	1200	1680
2	Four-Lane Divided	5400*(2700)*	1350	3780*(1890)*
3	Six-Lane Divided	8400*(4200)*	1400	5880*(2940)*
4	Eight-Lane Divided	13600*(6800)*	1700	9520*(4760)*
5	Ten-Lane Divided	20000*(10000)*	2000	14000*(7000)*

4.1. Capacity Analysis

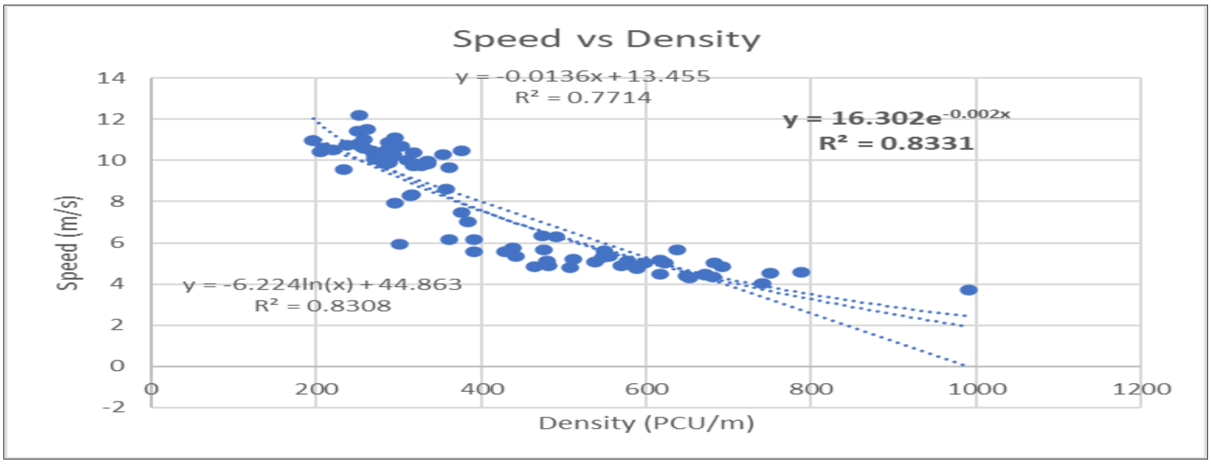

Figure 1 Speed Vs Density At Medchal Road

Different models like Greenshield, Greenberg and Underwood model was tried to developed speed flow curves for determination of Capacity. Through the data analysis it was found that Underwood model worked very well as it has higher R^2 value of 0.8331 when compared with other two models.

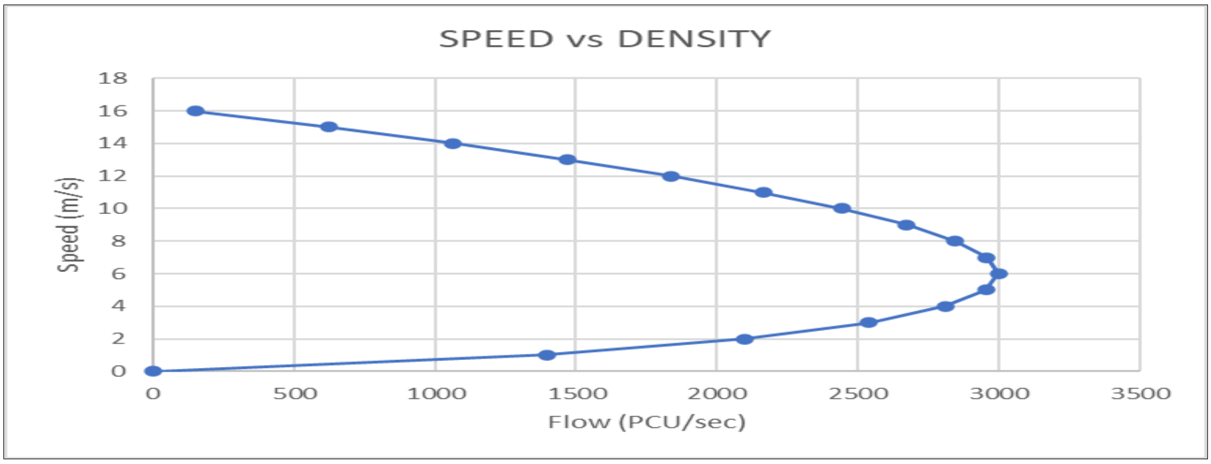

Figure 2 Speed Vs Density Graph Plot At Medchal Road

The capacity value obtained from the speed flow curve is 2998.98 PCU/sec from the field data.

From the analysis we observed the reduction in capacity on the medchal four lane divided is found to be decreased by 13.08449 %

So, Reduction in Capacity is = 13.08449%

4.2. Level of service

Level-of-Service(LOS) of a traffic facility is a concept introduced to relate the quality of traffic service to a given flow rate. Level-of-Service is introduced by HCM to denote the level of quality one can derive from a local under different operation characteristics and traffic volume. HCM proposes LOS as a letter that designate a range of operating conditions on a particular type of facility. Six LOS letters are defined by HCM, namely A, B, C, D, E, and F, where A denote the best quality of service and F denote the worst. These definitions are based on Measures of Effectiveness (MoE) of that facility. Typical measure of effectiveness include speed, travel-time, density, delay etc. There will be an associated service volume for each of the LOS levels. A service volume or service flow rate is the maximum number of vehicles, passengers, or the like, which can be accommodated by a given facility or system under given conditions at a given LOS.

Level of service is defined as a quantitative measure describing operational conditions. An analysis is done in order to determine the change in level of service of urban roads with increase in pedestrian traffic in combination with varying vehicular traffic. LOS is found out by taking the average travel speed of vehicles as percentage of free flow speed. The standards for choosing the LOS is based on IRC 106-1990. The average speed corresponding to each traffic volume range is found out for different pedestrian volume. This speed is expressed as a percentage of free flow speed of the ideal locations.

Table 4 LOS of multilane divided urban roads based on stream speed, V/C Ratio And FFS

LOS	**Volume/Capacity Ratio**	**Percentage of Free Flow Speed**
LOS A	≤ 0.15	≥ 84
LOS B	0.15 - 0.45	83 – 76
LOS C	0.46 - 0.75	75 - 59
LOS D	0.76 - 0.85	58 – 41
LOS E	0.86 - 1.00	40 - 22
LOS F	> 1.00	< 22

From the detail analysis we have done we obtained maximum speed of vehicle on the medchal four lane divided road.

Highest speed found is = 12.17 m/s (43.18 km/hr)

Which comes under LOS D. This LOS D is mostly approaching unstable flow. Speeds slightly decrease as traffic volume slightly increases. Freedom to maneuver within the traffic stream is much more limited and driver comfort levels decrease

5. Conclusion

Study was conducted to analyze in detail the impact of pedestrian movements on speed of four lane divided urban roads in developing countries. Analyses were conducted on speed variability observed on stretches with pedestrian movement.

- Speed prediction models were developed on pedestrian movement parameters and traffic composition. These models were found to be statistically sound, can be used for predicting speeds and therefore speed reduction caused by pedestrian movement.
- All the frictional parameters considered were found to significantly contribute, but negatively to speed which is logically correct. The frictional parameter considered includes the number of pedestrians walking along sides of carriage ways in case of pedestrian dense zones.
- Speed prediction models were employed to assess the impact of variations in pedestrian movements. Speed prediction models developed in the study can be used to determine the speed of traffic flow which is affected by pedestrian crossings.
- Thus, it is recommended that while planning urban road facilities, pedestrian crossings should be given due importance and placed accordingly so that its impact does not affect the traffic flow to a higher level there by reducing the speed of traffic flow.
- The base capacity for a four lane divided urban arterials from Indo HCM Manual is 3450 PCU/sec. Through the development of speed flow curves for Medchal road was 2998.98 PCU/sec. The reduction in capacity due to a bus stop was found to be 13 percent due to the pedestrians movement on the urban roads.
- Urban roads are usually designed for LOS C (IRC:106-1990). But because of pedestrian movement on the road, the level of service got worsen to LOS D, thus causing congestion and travel time delays.

The developed model can be used by the practicing engineers to estimate capacity of the section for any levels of pedestrian movement in traffic stream and subsequently planned the urban roadway policy and design.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that they have no conflict of interest.

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