EVALUATION OF SPEED - FLOW CHARACTERISTICS ON INDIAN HIGHWAYS

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Abstract

As the road transportation sector is the driving force of any country's economic development, it is most essential to carefully plan and evaluate the highway related projects. This can be accomplished by conducting economic analysis so as to utilize the available resources in an optimal way and provide efficient road network and enable the economy to grow with minimum hindrance. The speed - flow characteristics determine the fuel consumption and other cost components. Hence, it is necessary to understand the speed - flow characteristics, which directly influence the road user costs. In India, road transportation has come to play dominant role by virtue of its flexibility and the expansion that has taken place in the road network and vehicle technology in the last three decades. These radical changes in road network and vehicle technology have resulted in significant changes in speed - flow characteristics and hence, it is essential to study these changes in speed - flow characteristics of highways, which in turn would be useful in estimating the road user costs. Therefore, an attempt has been made in this paper to present the speed - flow characteristics on Indian highways in plain terrain and its changes over time.

Keywords: Basic desired speed; Free speed; Speed - flow relationships; Capacities
Topic: G01 Transport and Urban Development Issues

1. Introduction

Transportation is the driving force for the economic development of any country. In India road transportation is the major component of the domestic transport. Fast depleting physical and fiscal resources and ever increasing travel demand calls for careful planning for optimally utilising the resources. In this regard, the estimation of total transportation cost involved in road transportation is essential to evaluate the highway projects. The total transportation cost is the price a nation pays to exploit the natural resources and activities separated over space. The total transportation cost comprises of capital / initial cost of construction of the facility, periodic maintenance cost of the facility and road user costs. Out of this, road user costs constitute major proportion and account for about 70 - 90 % of the total transportation cost. The two elements of major importance in road user cost estimation are the speeds and the volume *(flow)* of traffic, and these factors are interrelated. The road user cost is affected greatly by the vehicle speeds and its changes. The speed factor is especially important because major objective of many proposed improvements is to provide for faster travel by increasing the operating speed or overall journey speed *[Winfrey, 1969]*. The speed - flow characteristics determine the fuel consumption and other cost components. In addition, the speed of travel also determines the travel time of the user and savings in travel time achieved by the user. Therefore it is imperative to note that the major feature affecting the road user costs is the speed - flow relationships on roads under given traffic and geometric conditions.

The design standards, especially geometrics and the riding quality directly influence the operating speeds and in-turn influence the road user costs. On rural highways, when the traffic flow is low, the vehicles can move freely without hindrance from other vehicles in the stream. As the flow increases, the vehicles cannot sustain their free speeds due to interaction with other vehicles. This leads to increase in travel time for the vehicles thereby adding to the road user costs.

Figure 1 presents a typical picture of speed - flow relationship of a carriageway of the road. In the recent decade, the automobile industry in India has undergone tremendous changes leading to manufacturing of more fuel-efficient and high technology vehicles that are capable of achieving very high speeds. The road design standards have also undergone significant changes due to the special emphasis laid by the Indian government towards providing better quality roads. Therefore, it was considered necessary to take a look at the changing trends of operating speed - flow characteristics on highways of India. In this paper an attempt is made to study the speed - flow characteristics *(i.e. Basic Desired Speeds, Free Speeds and Speed - Flow Relationships)* on Indian highways in plain terrain and their changing trends with time. This is done by drawing comparison of speed - flow characteristics observed through studies conducted in the years 1982, 1992 and 2001 as a part of the Road User Cost Studies conducted in India and from here onwards these studies will be referred as RUCS-1982, URUCS-1992 and URUCS-2001 respectively in this paper.

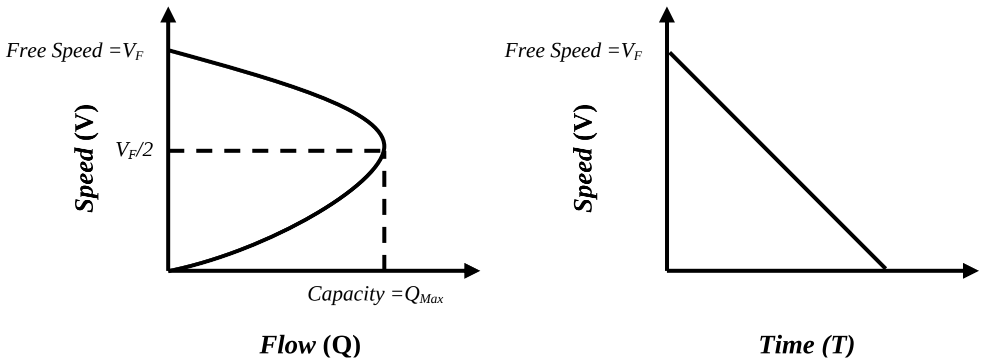

Figure 1 typical speed - flow relationships

The first section of this paper deals with the results of the Basic Desired Speed *(BDS)* studies and their statistical analysis. In the second section, the results of the Free Speed studies are described along with the statistical significance of the changes in free speeds. In the third section, the speed - flow relationships for varying road widths on plain terrain along with the capacity norms are analysed. The final section contains both conclusions and future directions for research emerging out of this analysis.

2. Basic desired speeds

Basic Desired Speed *(BDS)* is defined as the speed at which drivers desire to travel on an ideal two-lane bi-directional rural highway when there are no interruptions due to traffic and the speed is not constrained by geometrics of highway.

2.1 Methodology

The efforts were made to repeat the BDS studies on the same sites chosen in the earlier studies *[CRRI, 1982 and Kadiyali, 1992]* so as to assess the changes that might have occurred over the elapsed period. Accordingly, four test sections were chosen for BDS study given in Table 1. The sites for the BDS study were selected on straight level tangent sections of two and four-lane carriageway possessing good shoulders and excellent riding quality with the sight distance being more than 600 meters.

Table 1. Test sections for basic desired speed studies

Class of Road	Section / Road	Location
NH-45	Chennai - Trivandrum	Km 29/400
NH-45	Chennai - Trivandrum	Km 98/600
NH-2	Delhi - Kolakta	Km 55/000
NH-8	Delhi - Jaipur	Km 18/000

The BDS of vehicles of different types were measured at the selected sites using Pro Laser Infrared Radar (*Light Detection and Ranging*) speed meters. To account for the heterogeneous mix of the traffic, vehicles were appropriately classified so as to provide compatibility of the study results over time. The vehicle classification adopted include: Two Wheelers, Old Brand *(OB)* Cars, New Brand *(NB)* Cars *(classified into 3 categories based on engine capacity)*, Buses, Light Commercial Vehicles *(LCV)*, Heavy Commercial Vehicles *(HCV)*. The number of measurements of each vehicle class was kept to a minimum of 40 to obtain statistically reliable results. The observed speeds of vehicles were classified with intervals of 5 Kmph to determine the frequency distribution of vehicles as per speed. The mean BDS and standard deviation values were calculated from the frequency distributions. Further, an attempt was made to check the validity of the data of different vehicles by fitting the normal distribution curves to the observed frequency distribution. Also, normal approximation test was carried for the comparable data sets so as to check the significance of the changes in mean BDS.

2.2 Changes in BDS

A comparison of the observed BDS *(mean speeds)* and their respective standard deviation and coefficient of variation with the previous studies *[CRRI, 1982 and Kadiyali, 1992]* for different vehicle classes on two-lane section are given in Table 2.

From the above table, it could be inferred that the BDS for corresponding vehicle classes on two-lane carriageways have increased drastically *(ranging from 10 - 30 %)* from 1982 to 1992. But at the same time, the increase in BDS from 1992 to 2001 is of the order of 1 percent only. A comparison of BDS on four lane divided carriageways with paved shoulders is given in Table 3.

2.3 Statistical analysis of BDS

To arrive at the logical conclusion about the speed increase, a statistical test in the form of normal approximation test *[Pignatoro, 1973]* was carried out for 95% significance level for the corresponding vehicle classes *[CRRI, 1982 and Kadiyali, 1992]*.

It was observed from the statistical analysis that the speed increase is found to be statistically significant between 1982 and 2001 and also between 1982 and 1992 across all the vehicle types for two-lane carriageway. At the same time, it was noted that the increment in mean BDS of the corresponding vehicle classes were not significantly different between 1992 and 2001. Similarly, the normal approximation test at 95% confidence limits revealed that there is no significant increase in BDS values of URUCS-2001 *[CRRI, 2001]* across corresponding vehicle types on four-lane divided carriageways as compared to two lane bi-directional carriageways indicating the consistency of speeds over space.

Table 2. Comparisons of basic desired speeds of vehicles on two lane carriageway with paved shoulders

S.No.	Vehicle Type	Observed Basic Desired Speeds (KMPH)										
		RUCS-1982 Statistics			URUCS -1992 Statistics				URUCS - 2001 Statistics			
					Chennai - Villupuram [N.H. 45]				Chennai - Villupuram [N.H. 45]			
		Mean	*Standard Deviation*	*Coefficient of Variation*	*No. of Observations*	*Mean*	*Standard Deviation*	*Coefficient of Variation*	*No. of Observations*	*Mean*	*Standard Deviation*	*Coefficient of Variation*
1	**Two-Wheelers**	**48.8**	**8.95**	**0.18**	**89**	**54.0**	**11.77**	**0.22**	**57**	**55.0**	**9.77**	**0.18**
2	**Old Brand Vehicles****											
a.	**Cars**	**62.5**	**12.60**	**0.20**	**279**	**71.4**	**10.79**	**0.15**	**153**	**71.3**	**13.47**	**0.19**
b.	**Jeeps/Vans**								**60**	**72.7**	**6.61**	**0.09**
3	**New Brand Vehicles**	**-**	**-**	**-**	**95**	**96.3**	**9.27**	**0.10**				
a.	**Category - I[1]**								**65**	**80.0**	**10.71**	**0.13**
b.	**Category - II[2]**								**62**	**83.0**	**12.46**	**0.15**
c.	**Category - III[3]**								**54**	**97.5**	**12.05**	**0.12**
4	**Buses**	**56.1**	**8.80**	**0.16**	**210**	**72.8**	**8.34**	**0.12**	**213**	**72.5**	**6.79**	**0.09**
5	**Light Commercial Vehicles**	-			**74**	**71.5**	**11.61**	**0.16**	**79**	**70.0**	**11.51**	**0.10**
6	**Heavy Commercial Vehicles**											
a.	**Empty**	**50.9**	**9.18**	**0.18**	**100**	**71.4**	**10.65**	**0.15**	**49**	**69.0**	**7.91**	**0.11**
b.	**Loaded**				**108**	**60.4**	**8.99**	**0.15**	**146**	**60.5**	**9.17**	**0.15**

Table 3: Comparisons of basic desired speeds of vehicles on four lane divided carriageway with paved shoulders

S.No.	Vehicle Type	Observed Basic Desired Speeds in URUCS - 2001 (in KMPH)											
		Chennai - Villupuram (N.H.45)				Delhi - Palwal (N.H.2)				Ahmedabad - Vadodara (N.H.8)			
		No. of Observations	*Mean*	*Standard Deviation*	*Coefficient of Variation*	*No. of Observations*	*Mean*	*Standard Deviation*	*Coefficient of Variation*	*No. of Observations*	*Mean*	*Standard Deviation*	*Coefficient of Variation*
1	**Two-Wheelers**	**183**	**57.0**	**9.4**	**0.17**	**387**	**57.5**	**10.67**	**0.19**	**194**	**57.5**	**9.24**	**0.16**
2	**Old Brand Vehicles****												
a.	**Cars**	**117**	**72.5**	**10.2**	**0.14**	**67**	**72.6**	**7.7**	**0.11**	**71**	**72.5**	**6.61**	**0.09**
b.	**Jeeps/Vans**	**72**	**72.8**	**8.4**	**0.12**	**74**	**77.4**	**10.0**	**0.13**	**104**	**75.5**	**9.17**	**0.12**
3	**New Brand Vehicles**												
a.	**Category - I[1]**	**88**	**81.8**	**7.5**	**0.10**	**311**	**82.0**	**10.44**	**0.13**	**224**	**83.0**	**9.69**	**0.12**
b.	**Category - II[2]**	**50**	**92.7**	**9.6**	**0.10**	**89**	**87.7**	**7.23**	**0.09**	**74**	**90.5**	**8.16**	**0.09**
c.	**Category - III[3]**	**59**	**98.8**	**7.3**	**0.07**	**170**	**97.9**	**8.24**	**0.08**	**88**	**97.7**	**7.91**	**0.08**
4	**Buses**	**169**	**72.8**	**8.2**	**0.11**	**109**	**72.7**	**6.97**	**0.10**	**245**	**72.4**	**6.64**	**0.09**
5	**Light Commercial Vehicles**	**62**	**72.3**	**8.7**	**0.12**	**78**	**70.5**	**7.9**	**0.11**	**183**	**72.1**	**7.04**	**0.10**
6	**Heavy Commercial Vehicles**												
a.	**Empty**	**104**	**70.5**	**8.6**	**0.12**	**102**	**68.5**	**7.68**	**0.11**	**170**	**68.1**	**7.21**	**0.11**
b.	**Loaded**	**64**	**62.6**	**7.6**	**0.12**	**51**	**62.0**	**7.42**	**0.12**	**79**	**61.0**	**7.62**	**0.12**

1 *- Category -I include Maruti-800, Maruti Van and Maruti Gypsy*
2 *- Category-II include New Technology Vans like Tata Sumo/Safari/,Toyota, Armada etc.*
3 *- Category-III include Maruti Zen, Fiat Uno,Santro, Matiz, Contessa, Maruti-1000/Esteem, Ceilo, Lancer, Honda City etc.*
*** - Includes Ambassador, Fiat, Mahindra Van, Standard van etc.*

3. Free speeds

The free speed of a vehicle is defined as the speed adopted by a driver under a given set of highway and environmental conditions when not restricted by other vehicles in the stream. In other words, free speed is the BDS subjected to the influence of the road geometrics and local environment. Generally, free speed conditions exist when traffic flow is very low and the drivers will have a fair degree of freedom in choosing the speed at which to drive. It is difficult to specify precisely the volume of traffic at which vehicle speeds can be termed as free speeds. Free speed is generally measured at very low level of flows; say 300 vehicles *[CRRI and IIT, Kanpur, 2000]* per hour per standard lane. In the present study, traffic volume less than 200 vehicles *[CRRI, 2001]* per hour were considered suitable for the determination of the free speeds.

3.1 Methodology

The RUCS-1982 study covered Free Speed Studies (*FSS)* at 76 sites located in different parts of the country whereas URUCS-1992 study covered FSS on a limited basis restricting to four sites for updation. In the present study, seven test sections shown in Table 4 across varying road widths were selected for conducting FSS in plain terrain.

Table 4. Test sections for free speed studies

Class of Road	Section / Road	Location
SH / MDR	Sripermbathur - Singaperumalkoil	Km 18/000
SH / MDR	Arakkonam - Sripermbathur	Km 4/400
NH-4	Chennai - Bangalore	Km 68/800
NH-8	Delhi - Jaipur	Km 67/300
NH-1	Delhi - Amritsar	Km 38/100
NH-45	Chennai - Trivandrum	Km 50/000
NH-7	Hyderabad - Bangalore	Km 80/100

The Pro Laser Instrumentation was employed to record the free speeds. The same vehicle classification identified for the BDS study was utilised for FSS also. The sample size and analysis procedure followed were also same as that of BDS study. The same analysis as that of BDS to determine the mean free speed and standard deviation values was carried out. Also, normal approximation test was carried for the comparable data sets so as to check the significance of the changes in mean free speeds.

3.2 Comparison of free speeds

A comparative evaluation of free speeds with the previous studies *[CRRI, 1982 and Kadiyali, 1992]* for varying road widths in plain terrain is discussed below:

- In the case of single lane carriageways *(possessing 3.5m width),* it was interesting to note (*refer Table 5)* that the free speeds have increased in the range of 1 - 23 % across the corresponding vehicle types.
- In the case of intermediate lane carriageways *(possessing 5.5m width),* it was observed *(refer Table 6)* that, the free speed increase was in the range of 16 - 40 % across different vehicle types.

Table 5. Comparison of free speeds of vehicles on single lane carriageway with earthen shoulders

S.No.	Vehicle Type	Free Speeds (KMPH)										
		RUCS-1982 Statistics			URUCS - 1992 Statistics Tambaram - Chennai (MDR)				URUCS - 2001 Statistics Arakkonam-Sriperambathur [MDR]			
		Mean	Standard Deviation	Coefficient of Variation	Number of Observations	Mean	Standard Deviation	Coefficient of Variation	Number of Observations	Mean	Standard Deviation	Coefficient of Variation
1	Two-Wheelers	39.1	9.06	0.23	97	45.2	10.18	0.23	90	45.3	9.80	0.23
2	Cars/Vans											
a.	New Brand Vehicles	-			91	52.5	9.96	0.18	43	62.0	9.20	0.15
b.	Old Brand Vehicles	48.4	9.42	0.19					42	57.5	8.60	0.15
3	Buses	47.5	6.50	0.14	100	48.2	7.98	0.17	42	52.5	8.06	0.16
4	Light Commercial Vehicles	-			79	51.4	8.37	0.16	53	52.0	9.90	0.19
5	Heavy Commercial Vehicles	38.5	6.43	0.17	71	44.4	7.44	0.17	49	47.5	8.90	0.19

Table 6. Comparison of free speeds of vehicles on intermediate lane carriageway with earthen shoulders

S.No.	Vehicle Type	Free Speeds (KMPH)										
		RUCS - 1982 Statistics			URUCS - 1992 Statistics Poonamalle - Avadi (MDR)				URUCS -2001 Statistics Arakkonam-Sriperambathur [MDR]			
		Mean	Standard Deviation	Coefficient of Variation	Number of Observations	Mean	Standard Deviation	Coefficient of Variation	Number of Observations	Mean	Standard Deviation	Coefficient of Variation
1	Two-Wheelers	41.4	8.80	0.21	99	45.0	7.90	0.18	157	45.0	9.93	0.22
2	Cars/Vans											
a.	New Brand Vehicles	-			34	48.80	8.26	0.17	68	65.5	9.21	0.14
b.	Old Brand Vehicles	46.9	9.60	0.20	74				45	57.5	9.27	0.16
3	Buses	43.2	7.97	0.18	73	44.2	7.23	0.16	42	56.5	8.34	0.15
4	Light Commercial Vehicles	-			71	40.7	8.58	0.21	60	56.8	9.00	0.16
5	Heavy Commercial Vehicles				160	42.8	6.38	0.15				
a.	Empty	44.2	5.67	0.13	89	45.7	7.35	0.16	52	53.0	7.11	0.13
b.	Loaded				71	42.3	5.41	0.13				

- As can be noticed from Table 7 that the free speeds on two-lane carriageways with earthen shoulders have registered steep increase *(ranging from 13 - 29 %)* as compared to RUCS-1982. At the same time, the increase in free speeds in the range of 1 - 7 % as compared to URUCS-1992 for the corresponding vehicle types. Table 8 presents free speed on two lane carriageways with paved shoulders for two test sections considered in the present study. When a comparative assessment was made between the free speeds in URUCS-2001 on two lane carriageways with and without paved shoulders *(refer Table 7 and 8)* it revealed that the speed increase is in the range of only 1.5 - 3.5 % across corresponding vehicle types.
- It could be noticed from Table 9 that the free speeds on four-lane divided carriageways have increased drastically *(ranging from 24 - 39 %)* as compared to RUCS-1982 study. At the same time, the increase in free speeds is only of the order of 0.5 - 7 % as compared to URUCS-1992 study for the corresponding vehicle types. Further, the free speeds on curves *(as shown in Table 9)* are expected to decrease by about 7 - 14 % across different vehicle types.

3.3 Statistical test for free speeds

As was done in the case of BDS, the normal approximation test *[Pignatoro, 1973]* at 95% significance levels on varying carriageway widths was applied for the corresponding vehicle classes to test whether the free speeds have registered any significant increase as compared to previous studies *[CRRI, 1982 and Kadiyali, 1992]*. The following could be inferred from this analysis:

- The increase in free speed between 1982 and 2001 and also between 1982 and 1992 across all the corresponding vehicle types was statistically significant for complete range of carriageway widths. Similarly, the free speed increase was found to be statistically significant between 1992 and 2001 in the case of single and intermediate lane carriageways across all the vehicle types except two wheelers. This could be directly attributed to better road conditions and improved vehicle technology. However, the quantum of increase in free speed is not statistically significant *(i.e. remained almost the same)* between 1992 and 2001 amongst corresponding vehicle types on two lane sections *(with earthen shoulders)* except old brand cars, buses and LCVs. This clearly reflects the rapid improvements in vehicle technologies which have taken place during this period in these vehicle types.
- In the case of two-lane carriageway with paved shoulders, the result clearly indicated that the free speeds across different vehicle classes are similar on all the road sections speed over space, thereby leading to the inference that the impact of geographical factors is insignificant.
- In the case of four-lane divided carriageway with paved shoulders, it could be seen that the free speed increase was statistically significant between 1982 and 2001 and also between 1982 and 1992 across different vehicle types. At the same time, it could be inferred that the increase in free speeds is not significant across different vehicle types *(except old brand cars/vans and LCVs)* between 1992 and 2001. This increase could be attributed to the improvement in vehicle technology in the case of old brand cars/vans and LCVs. Further, the statistical comparison made between the free speeds on straight and curved road sections reveals that the quantum of reduction in free speeds on curves is found to be statistically significant for all vehicle classes. This clearly demonstrates that the free speeds on curves are expected to decrease significantly irrespective of the vehicle type.

Table 7. Comparison of free speeds of vehicles on two lane carriageway with earthen shoulders

S.No.	Vehicle Type	Free Speeds (KMPH)										
		RUCS-1982 Statistics			URUCS - 1992 Statistics Chennai - Bangalore *(N.H.4)*				URUCS - 2001 Statistics Chennai - Bangalore *(N.H.4)*			
		Mean	*Standard Deviation*	*Coefficient of Variation*	*Number of Observations*	*Mean*	*Standard Deviation*	*Coefficient of Variation*	*Number of Observations*	*Mean*	*Standard Deviation*	*Coefficient of Variation*
1	Two-Wheelers	48.8	8.95	0.18	73	53.6	8.87	0.17	59	54.0	9.00	0.17
2	Old Brand Vehicles**											
a.	Cars	62.5	12.60	0.20	167	67.3	8.27	0.12	211	70.6	10.57	0.15
b.	Jeeps/Vans								73	68.0	11.30	0.17
3	New Brand Vehicles	-			95	85.6	11.54	0.13				
a.	Category - I[1]								115	75.0	11.71	0.16
b.	Category - II[2]								104	77.1	11.70	0.15
c.	Category - III[3]								94	86.0	10.50	0.12
4	Buses	56.1	8.80	0.16	122	62.9	7.19	0.11	260	67.0	8.48	0.10
5	Light Commercial Vehicles	-			73	63.1	8.25	0.13	148	67.5	9.94	0.15
6	Heavy Commercial Vehicles											
a.	Empty	50.9	9.18	0.18	80	64.0	7.97	0.12	115	65.4	10.31	0.16
b.	Loaded				84	56.3	8.23	0.15	95	55.5	9.97	0.18

1 *- Category -I include Maruti-800, Maruti Van and Maruti Gypsy*

2 *- Category-II include New Technology Vans like Tata Sumo/Safari/,Toyota, Armada etc.*

3 *- Category-III include Maruti Zen, Fiat Uno,Santro, Matiz, Contessa, Maruti-1000/Esteem, Ceilo, Lancer, Honda City etc.*

*** - Includes Ambassador, Fiat, Mahindra Van, Standard van etc.*

Table 8. Comparison of free speeds of vehicles on two lane carriageway with paved shoulders

S.No.	Vehicle Type	Free Speeds in URUCS - 2001 (KMPH)							
		Hyderabad - Jedcherla (N.H.7)				Ahmedabad - Vadodara (N.H.8)			
		Number of Observations	Mean	Standard Deviation	Coefficient of Variation	Number of Observations	Mean	Standard Deviation	Coefficient of Variation
1	Two-Wheelers	225	57.1	11.38	0.19	281	56.9	10.59	0.19
2	Old Brand Vehicles**								
a.	Cars	54	71.8	8.82	0.12	102	72.5	8.43	0.12
b.	Jeeps/Vans	60	68.0	8.32	0.12	74	72.5	8.93	0.12
3	New Brand Vehicles								
a.	Category - I[1]	109	77.5	10.28	0.13	183	77.5	8.70	0.11
b.	Category - II[2]	-				69	82.9	9.05	0.11
c.	Category - III[3]	84	88.0	10.73	0.12	59	87.7	10.54	0.12
4	Buses	207	67.8	10.72	0.16	187	67.7	10.88	0.16
5	Light Commercial Vehicles	146	68.5	9.46	0.14	174	67.7	9.82	0.15
6	Heavy Commercial Vehicles								
a.	Empty	59	67.7	7.53	0.11	340	67.5	9.14	0.14
b.	Loaded	374	56.6	10.91	0.19	121	56.8	8.20	0.14

1 - Category -I include Maruti-800, Maruti Van and Maruti Gypsy

2 - Category-II include New Technology Vans like Tata Sumo/Safari/,Toyota, Armada etc.

3 - Category-III include Maruti Zen, Fiat Uno,Santro, Matiz, Contessa, Maruti-1000/Esteem, Ceilo, Lancer, Honda City etc.

*** - Includes Ambassador, Fiat, Mahindra Van, Standard van etc.*

Table 9. Comparison of free speeds of vehicles on four lane divided carriageway with and without paved shoulders

S. No.	Vehicle Type	Free Speeds (KMPH)											
		RUCS - 1982 Statistics			URUCS-1992 Statistics			URUCS - 2001 Statistics					
		Delhi - Mathura (N.H. 2)@			Delhi - Karnal (N.H.1)			Delhi - Karnal (N.H.1)			Chennai - Villupuram (N.H. 45)#		
		Mean	Standard Deviation	Coefficient of Variation	Mean	Standard Deviation	Coefficient of Variation	Mean	Standard Deviation	Coefficient of Variation	Mean	Standard Deviation	Coefficient of Variation
1	Two-Wheelers	44.9	7.20	0.16	56.5	7.77	0.14	57.2	9.17	0.17	52.5	11.27	0.21
2	Old Brand Vehicles**												
a.	Cars	58.8	6.36	0.11	68.0	10.39	0.15	72.9	9.42	0.13	68.0	9.21	0.14
b.	Jeeps/Vans							72.8	9.48	0.13	68.1	9.80	0.14
3	New Brand Vehicles	-	-	-	91.8	12.66	0.14						
a.	Category - I[1]							77.9	9.79	0.13	70.5	8.60	0.12
b.	Category - II[2]							83.1	8.39	0.10	77.7	11.52	0.15
c.	Category - III[3]							92.4	9.76	0.11	85.5	10.10	0.12
4	Buses	54.3	7.04	0.13	75.3	9.59	0.13	75.4	9.57	0.14	68.1	7.50	0.11
5	Light Commercial Vehicles	-			69.6	8.69	0.12	73.9	10.33	0.14	65.0	11.87	0.18
6	Heavy Commercial Vehicles												
a.	Empty	48.7	6.71	0.14	67.0	7.60	0.11	67.7	10.78	0.16	62.0	10.30	0.13
b.	Loaded				62.6	8.58	0.14	62.9	9.23	0.10	55.0	10.60	0.19

1 *- Category -I include Maruti-800, Maruti Van and Maruti Gypsy*

2 *- Category-II include New Technology Vans like Tata Sumo/Safari/,Toyota, Armada etc.*

3 *- Category-III include Maruti Zen, Fiat Uno,Santro, Matiz, Contessa, Maruti-1000/Esteem, Ceilo, Lancer, Honda City etc.*

*** - Includes Ambassador, Fiat, Mahindra Van, Standard van etc.*

@ *In the 1982 study, this road section was only Four lane with Earthen Shoulders*

\# *This Section is specifically chosen for assessment of Free Speed Reduction on Curves*

4. Speed - flow relationships

One of the important aspects of the present studies is the determination of speed - flow relationships for different types of roads in India. The speed - flow relationships are the basis for the determination of the capacity of a road. The theoretical speed - flow curve is a parabola and maximum flow *(capacity)* supposed to occur at half the free speed *[TRB, 1995]*. The speed - flow studies were conducted for Indian conditions in 1982 and 1992 *[CRRI, 1982 and Kadiyali, 1992]*. As the road quality and vehicle technology have undergone tremendous changes, there is a need to reassess and evaluate the changing trends of the relationships between speed and flow on different road widths for present Indian traffic conditions. A critical comparison was made in URUCS-2001 study to assess the changing trends of the mathematical relationships for varying road widths on plain terrain with previous studies *[CRRI, 1982 and Kadiyali, 1992]*.

4.1 Methodology

The speed - flow studies were conducted at eight sites on plain terrain covering varying carriageway widths spread over the country. The test sections chosen were:

- Basirghat - Nazet
- Domgur - Dholagiri
- Sonepat - Rohtak *(SH-20)*
- Ambala - Amristar *(NH-1)*
- Hyderabad - Jedcherla *(NH-7)*
- Ahmedabad - Vadodara *(NH-8)*
- Delhi - Karnal *(NH-1)* at Km 54/000 and
- Delhi - Karnal at Km 34/000 and 134/000 *(NH-1)*

The study was conducted by employing Videography and Registration Plate methods for traffic flow and journey speed measurements respectively. The vehicle classification followed for speed - flow analysis comprised of Two wheelers, Old Brand Cars, New Brand Cars, Buses, LCVs and HCVs.

4.1.1 Videography method

This method was used for collection of data on classified traffic flow. A total of 6 hours of video recording *(3 hours each in the morning and evening covering peak and lean traffic flows)* was done under fair weather conditions. The video cassettes were then decoded so as to determine the classified traffic flows.

4.1.2 Registration plate method

In this method, entry and exit times of the vehicles over the predetermined trap length were recorded with the help of two synchronized stop clocks along with the registration numbers of the vehicles. The trap lengths of the road stretches selected for the speed measurements ranged between 600 m to 1800 m. The stop clocks were also synchronised with that of the video clock time so as to maintain the linkage between the two methods. Efforts were made to collect a minimum of 100 observations of speed measurements for each vehicle class at each site spread over the peak and off-peak hours.

4.2 Analysis of data

By noting the registration number and time of arrival and departure of the vehicles at the entry and exit points, the travel time over the selected trap length was determined and thereby the travel speeds. The Space Mean Speed *(SMS)* of the corresponding vehicle type was determined by grouping the observations falling within 1 or 5-minute interval as the case may be. The average time of travel for each category of vehicles in the particular time interval was calculated and the SMS of the particular mode was determined. The volume of traffic was later expanded into hourly traffic volume in Passenger Car Units *(PCUs)* per hour. The SMS values were in-turn related to the two-way *(or one-way as the case may be)* traffic flows in PCUs per hour. The one-way traffic flow *(i.e. in the respective direction of speed measurement)* was considered in the case of four-lane divided road.

4.3 Speed - flow equations

The speed - flow equations were developed for different vehicle classes by considering speed as the dependent variable and the corresponding flow *(in PCUs/hour)* as the independent variable. The comparative analysis of speed - flow relationships are presented in Table 10 to 15. The following inferences could be drawn from the above table.

- ✓ The calculated t-value of the coefficient and intercept in URUCS-2001 are significant while standard errors of both are negligible. Thus the regression models can be said to be statistically acceptable, as the calculated t-value of the regression coefficients and R^2 values are fairly good.
- ✓ It could be inferred that the free speeds of 2001 on two-lane carriageway with earthen shoulders, *(i.e. intercept values in the equations)* have increased by about 16 - 18 percent as compared to those of 1982 while the increase is negligible *(one percent)* as compared to those of 1992.
- ✓ The rate of fall in speeds of vehicles is found to be rapid in the case of roads with earthen shoulders as compared to that of paved shoulders. This is revealed by the lower values of the regression coefficient of traffic volume (*i.e. Q*) in the equations pertaining to roads with paved shoulders (*presented in Table 13*). This observation is quite reasonable and it is further supported by the free speed results, which indicate that the paved shoulders do provide a good cushion for efficient overtaking and crossing maneuvers.
- ✓ From the above observations, it can be concluded that the provision of hard shoulders on a two lane bi-directional road would retard the reduction of speeds with the increase in traffic flow meaning thereby implying higher capacities and better levels of services can be achieved with hard shoulders.
- ✓ The four-lane divided carriageway enables to increase the free speed in the range of 1 - 7 percent as compared to two lane bi-directional carriageway. In most of the vehicle types, the rate of decrease in speed *(i.e. slope)* with increase in volume is found to be lower in four-lane divided carriageway as compared to two lane bi-directional carriageway. The above observations suggest higher capacities and better levels of service can be achieved with divided carriageways for a given width of traffic lane.

Table 10. Comparison of speed flow equations in plain terrain *(Single lane carriageway with earthen shoulder)*

S. No.	Vehicle Type	RUCS - 1982 Equations	URUCS - 1992 Equations	URUCS - 2001 Equations
1	New Brand Cars	-	V = 49.98 - 0.041*Q	**V = 61.748 - 0.0562*Q** (15.475) (-5.609)@, R^2 = 0.759; (3.990,0.010)#
2	Old Brand Cars	V = 49.98 - 0.041*Q	V = 49.98 - 0.041*Q	**V = 57.232- 0.0477*Q** (22.488) (-9.420)@, R^2 = 0.824; (2.545,0.005)#
3	Buses	V = 46.92 - 0.032*Q	V = 46.92 - 0.032*Q	**V = 51.744 - 0.0476*Q** (15.297) (-5.336)@, R^2 = 0.542; (4.828,0.003)#
4	Light Commercial Vehicles	-	V = 48.97 - 0.040*Q	**V = 51.937 - 0.0510*Q** (19.337) (-7.563)@, R^2 = 0.792; (2.686,0.007)#
5	Heavy Commercial Vehicles	V = 42.45 - 0.024*Q	V = 42.45 - 0.024*Q	**V = 47.283 - 0.0373*Q** (16.462) (-5.556)@, R^2 = 0.756; (2.872,0.007)#
6	Two wheelers	-	V = 42.98 - 0.0350*Q	**V = 42.666 - 0.0300*Q** (44.246) (13.338)@, R^2 = 0.791; (0.962,0.002)#

Table 11. Comparison of speed flow equations in plain terrain *(Intermediate lane carriageway with earthen shoulder)*

S. No.	Vehicle Type	RUCS - 1982 Equations	URUCS - 1992 Equations	URUCS - 2001 Equations
1	New Brand Cars	-	V = 64.04 - 0.0203*Q	**V = 63.249 - 0.0210*Q** (52.684) (-10.833)@, R^2 = 0.751; (1.201,0.002)#
2	Old Brand Cars	V = 64.04-0.0203*Q	V = 64.04 - 0.0203*Q	**V = 57.177 - 0.0195*Q** (25.944) (-5.899)@, R^2 = 0.554; (2.204,0.003)#
3	Buses	V = 58.85-0.0173*Q	V = 58.85 - 0.0173*Q	**V = 56.222 - 0.0130*Q** (24.080) (-3.976)@, R^2 = 0.387; (2.335,0.003)#
4	Light Commercial Vehicles	-	V = 53.15 - 0.0170*Q	**V = 56.282 - 0.0195*Q** (25.478) (-5.967)@, R^2 = 0.569; (2.209,0.003)#
5	Heavy Commercial Vehicles	V = 51.05-0.0099*Q	V = 51.05 - 0.0099*Q	**V = 52.350 - 0.0186*Q** (35.490) (-8.827)@, R^2 = 0.780; (1.475,0.002)#
6	Two wheelers	V = 53.10-0.0170*Q	V = 53.10 - 0.0170*Q	**V = 47.849 - 0.0109*Q** (36.185) (-5.811)@, R^2 = 0.791; (0.962,0.002)#

Note: V = Speed of Vehicle (kmph); Q = Two-way Flow in PCU/hr (in the direction of speed measurement); **@** *= represent the calculated t-value of the intercept and the coefficient respectively;* **#** *= represent the Standard Error of the Intercept and the Coefficient respectively;* **-** *= Not considered;*

Table 12. Comparison of speed flow equations in plain terrain *(Two lane carriageway with earthen shoulder)*

S. No.	Vehicle Type	RUCS - 1982 Equations	URUCS - 1992 Equations	URUCS - 2001 Equations
1	New Brand Cars	-	V = 85.450-0.0170*Q	**V = 85.386 - 0.0178*Q** (38.054) (-11.468)@, R^2 = 0.785; (2.238,0.002)#
2	Old Brand Cars	V = 59.05-0.0087*Q	V = 67.960-0.0120*Q	**V = 70.176 - 0.0092*Q** (55.547) (-9.801)@, R^2 = 0.390; (1.263,0.001)#
3	Buses	V = 58.06-0.0089*Q	V = 66.790-0.0130*Q	**V = 67.457- 0.0079*Q** (13.972) (-2.531)@, R^2 = 0.198; (4.828,0.003)#
4	Light Commercial Vehicles		V = 65.960-0.0130*Q	**V = 67.400 - 0.0060*Q** (41.830) (-5.078)@, R^2 = 0.244; (1.611,0.001)#
5	Heavy Commercial Vehicles	V = 50.09-0.0065*Q	V = 58.960-0.0079*Q	**V = 59.295 - 0.0083*Q** (11.025) (-2.355)@, R^2 = 0.257; (5.378,0.004)#
6	Two wheelers	-	V=51.580-0.0069*Q	***

Table 13. Comparison of speed flow equations in plain terrain *(Two lane carriageway with paved shoulder)*

S. No.	Vehicle Type	RUCS - 1982 Equations	URUCS - 1992 Equations	URUCS - 2001 Equations
1	New Brand Cars	-	V=87.160-0.0076*Q	**V=86.638 + 0.0072*Q** (226.175) (-24.950)@, R^2 = 0.668; (0.383, 0.0003)#
2	Old Brand Cars	-	V=68.390-0.0040*Q	**V=69.069 + 0.0052*Q** (95.600) (-10.713)@, R^2 = 0.245; (0.722, 0.0010)#
3	Buses	-	V=69.740-0.0036*Q	**V=70.118 + 0.0071*Q** (158.967) (-20.200)@, R^2 = 0.688; (0.441, 0.0004)#
4	Light Commercial Vehicles	-	V=70.060-0.0064*Q	**V=70.172 + 0.0061*Q** (159.02) (-20.203)@, R^2 = 0.688; (0.441, 0.0004)#
5	Heavy Commercial Vehicles	-	V=60.350-0.0062*Q	**V=61.631 + 0.0062*Q** (129.897) (-17.051)@, R^2 = 0.363; (0.474, 0.0004)#
6	Two wheelers	-	V=54.870-0.0063*Q	**V=55.243 + 0.0073*Q** (73.803) (-12.760)@, R^2 = 0.554; (0.749, 0.0006)#

*Note: V = Speed of Vehicle (kmph); Q = Two-way Flow in PCU/hr (in the direction of speed measurement); **@** = represent the calculated t-value of the intercept and the coefficient respectively; **#** = represent the Standard Error of the Intercept and the Coefficient respectively; - = Not considered; *** = Sufficient sample was not available to fit the model*

Table 14. Comparison of speed flow equations in plain terrain *(Four lane divided carriageway with earthen shoulder)*

S. No.	Vehicle Type	RUCS - 1982 Equations	URUCS - 1992 Equations	URUCS - 2001 Equations
1	New Brand Cars	-	V = 81.210-0.0079*Q	**V = 85.140 - 0.0091*Q** (92.401) (-10.502)[@], R2 = 0.385; (0.921, 0.012)[#]
2	Old Brand Cars	V=51.84-0.00254*Q	V = 66.520-0.0096*Q	**V = 70.430 - 0.0077*Q** (53.066) (-5.239)[@], R2 = 0.247; (1.327, 0.0015)[#]
3	Buses	V=46.35-0.00184*Q	V = 63.440-0.0044*Q	**V = 70.883 - 0.0069*Q** (49.327) (-4.106)[@], R2 = 0.167; (1.438, 0.0017)[#]
4	Light Commercial Vehicles	-	V = 62.530-0.0034*Q	**V = 70.744 - 0.0080*Q** (35.889) (-3.875)[@], R2 = 0.211; (1.971, 0.0020)[#]
5	Heavy Commercial Vehicles	V=44.7-0.00127*Q	V = 60.010-0.0086*Q	**V = 62.411 - 0.0111*Q** (38.609) (-6.317)[@], R2 = 0.317; (1.616, 0.0018)[#]
6	Two wheelers	V=59.89-0.00083*Q	V = 57.40 - 0.0072*Q	**V = 58.675-0.0075*Q** (61.402) (-9.313)[@], R2 = 0.483; (0.956, 0.0008)[#]

Table 15. Comparison of speed flow equations in plain terrain *(Four lane carriageway with paved shoulder)*

S. No.	Vehicle Type	RUCS - 1982 Equations	URUCS - 1992 Equations	URUCS - 2001 Equations
1	New Brand Cars	-	V = 81.210-0.0079*Q	**V = 85.140 - 0.0091*Q** (92.401) (-10.502)[@], R2 = 0.385; (0.921, 0.012)[#]
2	Old Brand Cars	V=51.84-0.00254*Q	V = 66.520-0.0096*Q	**V = 70.430 - 0.0077*Q** (53.066) (-5.239)[@], R2 = 0.247; (1.327, 0.0015)[#]
3	Buses	V=46.35-0.00184*Q	V = 63.440-0.0044*Q	**V = 70.883 - 0.0069*Q** (49.327) (-4.106)[@], R2 = 0.167; (1.438, 0.0017)[#]
4	Light Commercial Vehicles	-	V = 62.530-0.0034*Q	**V = 70.744 - 0.0080*Q** (35.889) (-3.875)[@], R2 = 0.211; (1.971, 0.0020)[#]
5	Heavy Commercial Vehicles	V=44.7-0.00127*Q	V = 60.010-0.0086*Q	**V = 62.411 - 0.0111*Q** (38.609) (-6.317)[@], R2 = 0.317; (1.616, 0.0018)[#]
6	Two wheelers	V=59.89-0.00083*Q	V = 57.40 - 0.0072*Q	**V = 58.675-0.0075*Q** (61.402) (-9.313)[@], R2 = 0.483; (0.956, 0.0008)[#]

Note: V = Speed of Vehicle (kmph); Q = One-way Flow in PCU/hr (in the direction of speed measurement); **@** *= represent the calculated t-value of the intercept and the coefficient respectively;* **#** *= represent the Standard Error of the Intercept and the Coefficient respectively;* **-** *= Not considered;*

5. Free speeds of vehicles

It was considered to validate the speed - flow relationships by comparing the observed free speeds of different vehicle classes with the intercepts obtained from the above speed - flow equations of varying road widths. Table 16 presents the comparison of the observed free speeds with the intercepts obtained from the speed - flow equations of URUCS-2001. It could be seen from this table that by and large, the intercepts developed independently from the speed - flow data are very close to the observed free speed values for a given carriageway width. This observation suggests that the developed speed - flow equations are valid and accurate.

Table 16. Comparison of free speed with intercept on speed - flow curves

S.No	**Road Category**	**Vehicle Type**	**Observed Free Speed** *(in kmph)*	**Intercepts Observed on Speed - flow Equations** *(in kmph)*
1	Single Lane Carriageway with Earthen Shoulders	a. NB Cars	62.0	61.8
		b. OB Cars	57.5	57.2
		c. Buses	52.5	51.7
		d. Two Wheelers	42.8	42.7
		e. LCVs	52.0	52.0
		f. HCVs	47.5	47.3
2	Intermediate Lane Carriageway with Earthen Shoulders	a. NB Cars	65.5	63.3
		b. OB Cars	57.5	57.2
		c. Buses	56.5	56.2
		d. Two Wheelers	45.0	47.9
		e. LCVs	56.8	56.3
		f. HCVs	53.0	52.4
3	Two Lane Carriageway with Earthen Shoulders	a. NB Cars	86.0	85.4
		b. OB Cars	70.6	70.2
		c. Buses	67.0	67.5
		d. Two Wheelers	54.0	-
		e. LCVs	67.5	67.4
		f. HCVs	60.5	59.2
4	Two Lane Carriageway with Paved Shoulders	a. NB Cars	87.7	88.3
		b. OB Cars	72.5	69.1
		c. Buses	67.7	69.8
		d. Two Wheelers	56.8	55.2
		e. LCVs	67.7	70.2
		f. HCVs	62.2	61.6
5	Four Lane Divided Carriageway with Paved Shoulders	a. NB Cars	92.4	92.8
		b. OB Cars	72.9	72.9
		c. Buses	75.2	76.1
		d. Two Wheelers	57.2	56.6
		e. LCVs	73.9	70.5
		f. HCVs	65.3	62.5

6. Capacity norms

The capacity of various categories of roads and recommended design service volumes deduced out of URUCS-2001 are given in Table 17.

Table 17. Recommended design service volumes and capacity for rural highways in plain terrain

Road Width	Capacity (PCUs/day)		Suggested Design Service Volume (PCUs/day)	Design Service Volume Recommended by IRC (PCUs/day)
	A*	B**		
a) Four Lane Divided Carriageway With Paved Shoulders	93000	116250	40000	40000
b) Four Lane Divided Carriageway With Earthen Shoulders	70000	90000	35000	35000
c) Two Lane Carriageway With Paved Shoulders	30000	40000	17250	17250
d) Two Lane Carriageway With Earthen Shoulders	25000	31350	15000	15000
e) Intermediate Lane Carriageway With Earthen Shoulders	16000	20000	6000	6000
f) Single Lane Carriageway With Earthen Shoulders	6000	7500	1000	1000

** Values under A refer to peak hour traffic of 10 percent; ** Values under B refer to peak hour traffic of 8 percent*

From the above table, the following could be inferred:

- The capacity of a single lane road in plain terrain is estimated to be in the range of 6000 - 7500 PCUs/day, which gives a design service volume of 3000 - 3700 PCUs/day. The values recommended by Indian Roads Congress *[IRC, 1990]* are 900 - 1800 PCUs/day and appear to be very much on the lower side.
- The capacity of an intermediate lane road in plain terrain is estimated to be in the range of 16000 -20000 PCUs/day, thus yielding a design service volume of 8000 - 10000 PCUs/day. This is higher than the value of 6000 PCUs/day recommended by IRC *[IRC, 1990]*.
- The capacity of a two lane bi-directional road with earthen shoulders in plain terrain is around 31,000 PCUs/day. With B-Level of Service, the design service volume evolved from this study is 12500 - 16000 PCUs/day, which is in close agreement with IRC guidelines *i*.e. 15000 PCUs/day *[IRC, 1990])*.
- When paved shoulders are provided on two lane carriageways in plain terrain, the capacity increases by more than 30 per cent. This reiterates the finding of URUCS-1992 study. At the same time, it may be recalled that the IRC Guidelines *[IRC, 1990]* recommends an increase of 15 percent in capacity, if paved shoulders are provided. In the light of the above results, the capacity guidelines for this category of road may have to be reviewed.
- The capacity of a four-lane divided carriageway with paved shoulders in plain terrain is in the range of 90,000 - 120,000 PCUs/day thus yielding a design service

volume of 45000 - 60000 PCUs/day/direction for this category of road under LOS-B. This is higher than the value of 40000 PCUs/day recommended in the IRC Guidelines *[IRC, 1990]*.

- When paved shoulders are omitted in the case of four lane divided carriageways, the maximum flow on four-lane carriageways in plain terrain is found to be 70,000 - 90,000 PCUs/day. Considering the B-Level of Service, the design service volume is 35000-45000 PCUs/day/direction. It is to be noted that this capacity value conforms to the recommended values of IRC *[IRC, 1990]* for this category of road. From this analysis, it can be noted that the provision of paved shoulders increases the capacity of the four-lane divided carriageways by about 25 percent.

7. Conclusions

7.1 Basic desired speeds

- The Basic Desired Speeds for corresponding vehicle classes on two lane carriageways are observed to have increased drastically *(ranging from 10 - 30 %)* as compared to RUCS-1982 while this increase is negligible *(about 1 %)* as compared to URUCS-1992. This marginal increase in BDS is further corroborated from the results of the normal approximation test, which revealed that the mean BDS of all the corresponding vehicle classes are not significantly different as compared to URUCS-1992 values.
- The statistical tests have revealed that the BDS on four-lane divided road with paved shoulders is not appreciably different as compared to the BDS on two-lane carriageway with paved shoulders across different vehicle classes. This corroborates the argument that the optimum BDS of a particular vehicle class can be achieved by the provision of properly paved and surfaced shoulders on a two lane road section itself. From this, it can be further stated that the provision of four-lane carriageway with paved shoulders would be more in the interest of safety *(due to the avoidance of any head-on collisions)* rather than enhancing the BDS and capacities at higher volumes of traffic.

7.2 Free speeds

- In the case of single lane carriageways, it is interesting to note that the free speeds have increased in the range of 1 - 23 % across the comparable vehicle types (*except two wheelers)* over the period of two decades *[CRRI, 1982 and Kadiyali, 1992]*.
- Similarly, in the case of intermediate lane carriageways, it is inferred that the free speed increase is of the order of 16 - 40 % across different vehicle types over the same period. The above increase in free speeds could be attributed to the improved road conditions and vehicle technology.
- It can be noticed that the free speeds on two-lane carriageways *(on plain terrain)* have increased drastically *(ranging from 13 - 29 %)* as compared to RUCS-1982 study while the increase in free speeds from 1992 is only of the order of 1 - 7 % for the corresponding vehicle types.
- It could be inferred from the results of the normal approximation test that the mean free speeds of old brand cars, buses and LCVs are significantly different as compared with 1992 values. This can be attributed to the improved technology of the vehicles.
- Free speeds of new brand cars are 21 to 28 % higher than that of old brand cars on two lane and four lane roads. However, a similar comparison on narrow roads reveals that the difference is of the order of 8 % on single lane and 14 % on intermediate lane as constraint of width governs the speeds of operation.

- In the case of two-lane carriageway with paved shoulders, the result clearly indicated that the free speeds across different vehicle classes are similar on all the road sections over space thereby leading to the inference that the impact of geographical factors is insignificant.
- In the case of four-lane divided carriageway with paved shoulders, the statistical comparison between the free speeds on straight and curved road sections reveals that the quantum of reduction in free speeds on curves is found to be statistically significant for all vehicle classes. This clearly demonstrates that the free speeds on curves are expected to decrease significantly irrespective of the vehicle type.

7.3 Speed - flow relationships and capacity norms

- The speed - flow relationships developed for varying carriageways in plain terrain revealed that they are statistically significant and hence they could be used with assurance for fixing capacity norms of carriageways in plain terrain.
- From the capacity norms evolved in the present study, it could be concluded that the capacities of the various categories of roads recommended by IRC are reasonable for the present till more evidence becomes available.
- The speed - flow studies conducted in the present study are mainly confined to plain terrain and hence, there is a need to carry out similar studies in rolling and hilly terrains.

8. Limitations

The results presented in this paper have the following limitations:

i) Free speed studies covered in URUCS-2001 is limited to plain terrain and such the findings can not be applied to rolling terrain.

ii) In the speed - flow equations, the traffic flow is represented in terms of Passengers Car Units *(PCUs)*. For converting the actual flows into PCUs, the factors recommended by IRC have been used. There is need for research to validate the appropriateness of these values.

9. Suggestions for further work

In order to cover the shortcomings and data gaps that have been observed, the following further work is suggested: -

i Free speed studies should be undertaken on the following road types on priority basis:
  - Rolling terrain: Single lane, Intermediate lane, Two lane and Four-lane roads
  - Hilly terrain: Single lane, Intermediate lane, Two lane and Four-lane roads

ii Basic Desired speed and Free Speed studies should be taken up periodically to establish the trends of speed rise and to capture the effect of better roads and technological upgradation of vehicles.

iii Speed - flow studies should be taken up on all types of carriageway widths on rolling and hilly terrain.

iv The speed - flow studies reported in this work have lead to capacity values slightly higher than those being adopted in the country. More studies need to be undertaken to cover a variety of traffic mix to further confirm these results.

v The speed - flow study on four lane carriageways could not cover traffic conditions sufficient to create conditions of congestion. It is suggested that more work needs to be done in this regard, through systematically planned experiments.

Acknowledgements

The authors are thankful to Director, Central Road Research Institute, New Delhi for his permission to publish this paper for WCTR 2004. The authors are thankful to the officials of MoRT&H, New Delhi for their cooperation during the field studies. The authors would like to place on record the association and help rendered by Sh. A. N. Ramalingaiah, Sh. Sher Singh, Sh. S. K. Ummat and other colleagues of CRRI during the study.

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