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EFFECT OF SHOULDER AND SLOW MOVING VEHICLES ON CAPACITY OF A ROAD

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Abstract— **Shoulder of a road supplements the role of a pavement for accommodating vehicles for the purpose of crossing, overtaking or parking whenever the main pavement is restricted in space. Condition of shoulder and its width affects speed of vehicles, capacity of the road and safe vehicle operation on the road. Similarly, slow moving vehicles of the traffic stream affect the speed, capacity and vehicle operation on the road. This paper presents an over view of the main studies taken up in the past to determine the effect of shoulder condition on capacity of a road. The effect of slow moving vehicles on capacity of a road is also presented. It is found that capacity of a road reduces as the shoulder width reduces and its condition changes from good to poor. The slow moving vehicles in the traffic also reduce capacity of the road.**

Keywords— **Capacity, Slow moving vehicles, Shoulder, Speed-flow, Lateral clearance.**

I. INTRODUCTION

Highway capacity is used in the planning, design and efficient vehicle operation on the road. It is an important tool in planning new roads and deciding the improvements of the existing roads. It also helps in prioritising various competing highway projects. Highway capacity has been the subject of continuing research since long. Studies on this important aspect over a long period of time have resulted in the extensive literature. Highway capacity manuals of various developed countries especially the United States have been the main source of information on this all important subject of road capacity. However, the traffic conditions of advanced countries are more or less homogeneous whereas traffic is mostly heterogeneous in developing countries like India. The concepts developed in advanced countries for homogeneous traffic have been applied to the mixed traffic conditions by various researchers in India and other developing nations. Among various factors like carriageway width, traffic mix, speed of traffic, features of the road and other roadway and traffic conditions that affect the capacity of a road, shoulder condition and the proportion of slow moving vehicles in the traffic stream have also been found to affect the capacity of a road. The following sections review the literature related to these aspects of highway capacity.

II. LITERATURE REVIEW

(A) Shoulder Condition

Taragin and Echardt (1953) [1] studied the effect of shoulder on speed. They also studied the lateral placement of motor vehicles on the road. They conducted the study on 6m wide and lesser width 2-lane pavements. They observed that for such roads shoulders of at least 1.2m of stabilized material should be constructed. The speed of moving vehicle was not substantially affected by the width of shoulder provided the shoulder was more than 1.2m wide. The lateral position of free moving vehicles and clearance between meeting vehicles had no significant relation to the shoulder width above 1.2 m. It was found that well-maintained grass shoulder had the same effect on speed and lateral position of moving vehicles as well- maintained gravel shoulder.

Belmont (1954) [2] considered three shoulder widths less than 6 ft, 6 ft and more than 6 ft and found that the accidents per mile increased with decreasing shoulder width with increase in average daily traffic. This was due to lesser capacity of the road with restricted shoulder width.

Stohner (1956) [3] found that reduction in accidents was observed as shoulder width increased, especially in 2000-6000 annual average daily traffic (AADT) range. No correlation was found for Annual Average Daily Traffic (AADT) less than 2000. This is attributed to the increased capacity of the road with increase in shoulder width.

Taragin (1958) [4] conducted a study on rural two-lane highway with 3.6m traffic lanes carrying light to moderate traffic volumes. He studied the section with gravel shoulders, bitumen paved shoulders having an appearance different from the travelled lane and section, where the shoulders were paved to their full width and were not different in appearance from lane. Several types of edge stripping were also studied. It was observed that although vehicle speeds were not affected by shoulder width and type, a relation between vehicle speed and lateral position did exist on section where the shoulder were paved to their full width. The average position of the slower vehicles regardless of its type was closer to the shoulder of the highway than that of faster vehicles. Commercial vehicles were found encroaching on shoulder to greater extent than passenger cars. This was more pronounced on section with paved shoulder, when there was no difference in appearance between the shoulder and traffic lanes. On section with paved shoulders that appeared different from the traffic lanes, the shoulder encroachment was 1/2 to 1/3 that of

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section where the traffic lanes and shoulders were of uniform colour and texture. Further, the concentration of lateral position of vehicle increased with increase in the difference in appearance between traffic lanes and shoulders.

Leong (1968) [5] observed speeds and capacity at 31 locations. The study was conducted on rural highways in New South Wales. The sites had varying lane and shoulder width. All studied sites had gravel shoulders. The data was analysed using multiple regression. The study showed that speed increased with increasing shoulder width. The shoulder width and type considerably affected the highway capacity also. With shoulder width reducing from 1.80 m to zero, the capacity was found to reduce by 14 %.

Prakash (1970) [6] also noticed that the road capacity was greatly affected by type and width of shoulder. The combined effect of lane width and edge clearance on highway capacity of two-lane road was found to be significant. It was observed that the capacity can be increased by 38.9 percent by making provision of 1.8 m wide shoulder on either side of a two-lane road. Similarly, presence of 1.2 m wide shoulder on either side of a two-lane road was found to have increased the capacity by 29.2 percent.

Turner et al. (1981) [7] carried out a study aimed at studying the attitude of drivers of moving vehicles to the use of shoulders. It was discovered that in normal circumstances, 5-13 percent vehicles used the shoulders. However, if the road markings were changed to imply the paved shoulder as traffic lane, then between 65 to 75 percent could use this lane, thereby greatly increasing the capacity of the road.

Turner et al. (1982) [8] observed that changing a shoulder to an additional traffic lane increases average speed. For a 2-lane road this increase by 5 percent. The increase in speed was for traffic more than 150 veh/hr. For 80 km/hr speed, the increase was 4 km/hr.

The effect of shoulder condition on capacity is not directly accounted for in various editions of the Highway Capacity Manuals (HCM). However, the effect of restricted lateral clearance and shoulder width is considered by HCM (1985) [9]. The capacity of a four-lane road reduces to 90% with the lateral clearance reducing from 1.83 m to zero for a 3.66 m lane road when the obstruction is on one side of the carriageway. For obstruction on both the sides, the capacity reduces to 81% with the same reduction in the lateral clearance (HCM, 1985) [9]. HCM (1994) [10] gives a reduction of 5.4 mph in free-flow speed of four-lane highways with the reduction in total lateral clearance from 3.66 m to zero. HCM (1985) provides for a reduction of 12% in capacity with the shoulder width reducing from 1.83 m to zero. HCM (2000) [11] gives a reduction in free-flow speed of 4.2 mph with the shoulder width reducing from 6 ft to zero.

Indian Roads Congress (IRC: 64, 1990) [12] provides for a reduction in capacity to 70% with the shoulder width reducing from 1.8 m to zero. IRC also provides for increase in capacity of two-lane roads by 15% by providing paved and surfaced shoulders of at least 1.5 m width on either side of the carriageway. In case well designed paved shoulders of 1.5 m width are provided, the design capacity of four-lane dual carriageway road increases from 35000 to 40000 PCU per day.

William and Reilly (1992) [13] brought out a summary of operational techniques. They showed the techniques were useful to increase level of service and capacity of 2-lane roads. They showed that the capacity increased by 2 % per one ft increase in shoulder width.

Kadiyali and Viswanathan (1993) [14] found the increase in design capacity of four-lane road in plain terrain from 40000 to 45000 PCU per day with the shoulder condition changing from earthen shoulders to paved shoulders. Similarly, for two-lane road the design capacity was found to increase from 12500 (earthen shoulders) to 15000 PCU per day (paved shoulders).

Kadiyali et al. (1981) [15] found the effect of shoulder conditions on free-flow speeds (FFS) of cars in case of single lane roads. They observed the FFS of cars reduces from 53.33 kmph (brick shoulder) to 48.39 kmph (earthen shoulder).

Chandra and Kumar (1996) [16] studied the effect of shoulder condition. The effect was observed on speed of different type of vehicles. They also studied the placement of vehicles on road during passing and overtaking manoeuvres. The study was conducted on single and 2-lane roads. It was observed that the average speed of vehicles on 2-lane road decreased by 5 to 8.5 percent for a given vehicle type for shoulder condition changing from bad to worse. The vehicles on single-lane road were observed to have reduced their speed during crossing and avoided coming closer than 20 cm to the pavement edge due to danger of overturning on broken shoulders. On two-lane roads, vehicles avoided coming closer than 55 cm to the pavement edge because of very bad condition of shoulders.

MOST (2000) [17] has mentioned the shoulder usage in its report. It has given that the average speed on the shoulder decreases with increase of flow and increase of percentage of trucks in the stream due to increased number of passings (crossing / overtaking operations) forcing the usage of shoulder. The shoulder usage in passing manoeuvre is only upto a flow of about 600 vehicle per hour where the usage is maximum.

Sachdeva (2004) [18] conducted speed flow studies on 4-lane, 2-lane, intermediate lane and single lane roads under varying conditions of shoulders ranging from surfaced, good, average and poor conditions and observed that The capacity of these roads is found to reduce by 4.7 %, 14.8 %, 35 % and 50.8 % respectively with shoulder conditions changing from good to poor.

(B) Slow Moving Vehicles

Slow moving vehicles have not been directly accounted for in the Highway Capacity Manuals obviously due to non-availability of such vehicles in advanced countries. However, the effect of heavy vehicles like trucks, buses and recreational vehicles on capacity of the roads is considered by the HCM (2000) [11] by introducing an adjustment factor. The value of this adjustment factor is taken as a function of

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equivalent passenger car values of the heavy vehicles and their proportion in the traffic stream. Higher the proportion of heavy vehicles in the traffic stream, the service volume of the road decrease.

Sachdeva (2004) [18] studied speed flow behaviour on 2-lane, intermediate lane and single lane roads under varying proportion of slow moving vehicles and observed that capacity of these roads respectively reduces by 1% to 20% with increase in SMV from 5% to 15% in the traffic stream.

Ramanayya (1988) [19] observed that the capacity values standardized in advanced countries cannot be applied to mixed traffic conditions of India. Under western condition it is assumed that a traffic lane is 3.8m and that one row of vehicles moves freely in one lane. Under mixed traffic flow on the other hand, a lane width may support two or three rows of narrow vehicles that is bicycles and mopeds. Further, in the west performance characteristics of a car dominate whereas under mixed traffic condition the overtaking behaviour utilising all available road width is the dominant mechanism.

Sarna et al. (1989) [20] revealed that the increasing percentage of heavy vehicles had negative impact on the service volumes and traffic carrying capacity of the road section. Similar effect was noticed for the slow moving vehicles and the parked vehicles.

Parker (1996) [21] observed that knowledge of traffic composition plays a vital role in determining capacity of a road. The proportion of heavy goods vehicles in a traffic stream has a major effect on capacity of the road. This effect is due to length, limited manoeuvrability and lower desired speed. Engine power to weight ratio also affect the capacity of a road. As the proportion of HGVs in the traffic stream increases, the capacity is found to reduce.

III. EFFECT OF SHOULDER CONDITION

From the aforementioned literature the effect of shoulder on speed, shoulder usage, capacity of road and safety on the road is found as given the table 1.

Table 1 Effect of Shoulder Condition

Study Ref.	Shoulder Condition	Effect
Effect on Speed of Vehicles		
[1]	Shoulder width > 1.2 m	No effect on speed
	Grass shoulder and gravel shoulder	Both shoulders have similar effect on speed
[8]	Shoulder conversion to additional traffic lane	Speed of vehicles increased by 5%
[10]	Lateral clearance of an object on shoulder reducing from 1.83 m to zero	Free flow speed reduces by 5.4 mph
[11]	Shoulder width reducing from 1.83m to zero	Free flow speed reduces by 4.2 mph
[15]	Shoulder changes from Brick shoulder to earthen shoulder	FFS reduces by 5.0 kmph
[16]	Shoulder condition changes from bad to worse on single lane road	Average speed of vehicles decreases by 5-8.5%
Effect on Usage of Shoulder		
[4]	Appearance of shoulder different from pavement	Usage of shoulder reduced to 50% - 33% of the section with similar appearance of shoulder and pavement
[7]	Normal marking between shoulder and pavement	Usage of shoulder was 5-13%
	Road marking changed to make paved shoulder as traffic lane	Usage of shoulder increased to 65-75%
[16]	Bad shoulders	Bad shoulders make vehicles move from edge of pavement. This distance is more on a 2-lane road than on a single lane road
[17]	Shoulder usage	Increases with flow and is maximum at a given flow level
Effect on Capacity of Road		
[5]	Shoulder width reducing from 1.8 m to zero	Capacity reduced by 14%
[6]	Paved shoulder of 1.2 to 1.8 m	Increased capacity by 29-39%
[9]	Lateral clearance of an obstruction on shoulder	Capacity reduced to 90-81%
	reducing from 1.83m to zero	
[12]	Shoulder width reducing from 1.83 m to zero	Capacity reduced by 30%
	Paved and surfaced shoulders of minimum width 1.5 m	Capacity increases by 15%
[13]	Increase in shoulder width	Capacity increases by 2% per one ft increase in shoulder width
[14]	Shoulder condition changing from earthen to paved	Capacity increases by 12.5% to 20% from 4-lane to 2-lane road
[18]	Shoulder condition changing from good to poor	Capacity reduces by 4.7 to 50.8% for 4-lane to single lane road
Effect on Road Accidents		
[2]	**Shoulder width reducing from1.8m**	**Accidents per mile increased**
[3]	**Increasing shoulder width for traffic>2000AADT**	**Accidents reduced**

IV. EFFECT OF SLOW MOVING VEHICLES

Similarly, the effect of slow moving vehicles on capacity of the road is found as given the table 2.

Table 2 Effect of Slow Moving Vehicles

Study Ref.	Presence of SMV	Effect
Effect on Capacity of Road		
[11]	Increasing percentage of heavy vehicles	Reduce the service volume that is design capacity of the road
[18]	Increasing percentage of slow moving vehicles from 5 to 15%	Capacity reduces by 1% to 20% from 2-lane to single lane
[20]	Increasing percentage of heavy vehicles / slow moving vehicles / parked vehicles	Reduce the service volume of the road
[21]	Increasing percentage of heavy goods vehicles	Reduce the capacity of the road

V. CONCLUSION

From the aforementioned contents the following main conclusions are drawn:

(i) Lesser shoulder width and poor condition of shoulders reduces the speed of vehicles.

(ii) Shoulder usage by the vehicles reduces as the appearance of shoulders becomes different from the pavement. Poor condition of shoulders also reduces their usage.

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