

# Effect of Side Friction on Travel Speed and Road User Cost in Rural Roads of India

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**ABSTRACT:** Land use pattern always have a significant impact on performance of highways of developing countries like India. In recent past Government of India invested substantial amount of money to improve the service level of various categories of roads in India. Several projects for widening and strengthening of roads have been taken up, surface condition has been improved but capacity and LOS has not been improved as expected because of abutting land use along the road alignment. One of the factors for not improving the LOS is the presence of side friction along rural highways. In developing countries like India presence of road-side markets at regular interval along rural roads is very common phenomenon. These road side market areas function as a pseudo bottleneck points to the fast moving traffic of highways. Road users have to incur indirectly the additional cost due to side friction in the form of vehicle operating and travel time cost. In literature review it is found that very few works have been carried out to understand effect of side friction on travel speed and Road User Cost. In the present paper an effort has been made to quantify the impact of roadside friction on travel speed and road user cost based on established relations and using side friction model developed for the study. Results have been demonstrated with the help of data collected from a 40.0km long road section consisting of sixteen road side markets in between.

**KEYWORDS:** Road side friction, market areas, friction elements, travel speed, vehicle operating cost, road user cost

## I. INTRODUCTION

Two-lane highways constitute substantial percentage of the total road network in the developing countries like India. The traffic operations on two-lane highways differ from the divided carriageway because of interaction between flows in two opposite directions.

Side friction in rural highways generated due to activities taking place on the earthen shoulder and sometimes in the carriageway edge which affect through traffic movement. In developing countries, road side markets along rural highways generally play the role of life line for the large number of rural population. These road side markets generally operate for 3-4 hours in a day at morning. These are mostly temporary or semi permanent type shops. Vendors used to bring vegetables, fish, fruits, grocery items etc through rickshaw van and cycles to these market areas. Local villagers come by walking, cycle or two wheelers to purchase their necessary items from these markets. They stand on the carriageway edge or earthen shoulder and purchase goods from vendors. During their marketing activities, they randomly cross the carriageway by walking and some time with their cycles. Random interactions occurred among pedestrians, non-motorized vehicles and fast moving vehicles.

World Bank and Asian Development Bank in many of their reports mentioned the dependency of rural populace on these road side markets in developing countries. In higher categories of rural highways (4-lane/6-lane divided carriageway) with high traffic volume, it is common practice to provide separate service lanes in built-up/market areas. However, in developing countries, substantial portion of rural highways are of two-lane single carriageway standard with low to medium traffic volume. No separate service road has been found in such roads.

In present study, a methodology has been proposed to express impact of side friction through an Index called Road Side Friction Index (RSFI). While traveling in rural highways, vehicles and passengers compelled to incur indirectly

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additional cost due to side friction. In present work, additional cost incurred for fuel, travel time, and commodity values have been considered. Results have been demonstrated with the help of data collected from a 40km long study section.

## II. LITERATURE REVIEW

In recent past many researchers carried out research work on impact of stops, average travel speed, acceleration/deceleration on fuel consumption, vehicular emission and vehicle operating cost. A few relevant research papers reviewed for the present work.

Rakha and Ding [1] used average speed as an important variable related to traffic and macroscopic emission models in the research work. They used average speed as a single traffic variable in estimating vehicle emissions. The aim of this research paper was to quantify the impact of vehicle stops on fuel consumption, emissions of hydrocarbons, carbon monoxide, oxides of nitrogen. The paper demonstrated that vehicle fuel consumption and emissions are sensitive to the combined level of vehicle acceleration and speed. Bokare and Maurya [2] demonstrated that there is significant difference in deceleration behaviour of various vehicle types. It was observed that vehicles having higher maximum speed have larger deceleration time, deceleration distance, maximum and mean deceleration rates during their deceleration manoeuvre. It was also found that vehicle's deceleration rate initially increases in deceleration manoeuvre. Then it attains the maximum deceleration and decreases afterwards. A dual regime model was proposed to explain deceleration behaviour over wide speed range of various vehicle types excluding car. A second order polynomial model was proposed for car. The Indonesian HCM [3] classifies side friction in to high and low levels and considers side friction correction factors to be incorporated in the calculation of free flow, saturation flow and capacity. The study conducted by Bang [4] identified side friction factors commonly observed along urban roads of Asian countries especially, Indonesia as pedestrians, vehicles stopping on shoulders and carriage ways, parking and access to road side premises. Side friction classes were defined for inter urban and urban roads on the basis of weights assigned to each side friction event. Koshy and Arasan [5] developed a microscopic simulation model to analyze the influence of bus stops on heterogeneous traffic flow with focus to reduction in traffic stream speed. They validated the model using traffic data collected at road side bus stops and bus bays. Chiguma [6] studied the effect of side friction factors on urban traffic performance indicators speed and capacity. He considered large number of study sections in urban areas and did macroscopic analysis as well as a microscopic analysis. In macroscopic analysis the combined effect of all side friction factors are considered where as in microscopic analysis the impact of each factor on traffic flow characteristics is taken. The side friction factors considered in this study includes pedestrians, bicycles, stopped and parked vehicles on road. The Highway Capacity Manual (HCM 2010) [7] includes some discussion on the effect of bus bay stops on capacity when buses go in and out of the stops. The parameters needed are the number of bus arrivals per hour at each bus stop and the average bus stopping time.

In the present study side friction generated from road side markets is the focus area. Interaction among friction elements, fast moving vehicles and slow moving vehicles occurred in a very random manner in market areas. A methodology is proposed to quantify side friction and it's impact on travel speed and road user cost.

## III. METHODOLOGY

Methodology proposed in the present research work starting from data collection, analysis, quantification of side friction, impact of side friction on travel speed and road user cost are explained below;

### Field data collection

All field data related to side friction, speed and traffic have been collected by trained enumerators in pre-designed format under the guidance of the authors. Three study sections have been selected such a manner that there should be no intermediate intersections and traffic and friction data could be obtained for wide range. Details of three study section are shown in Table 1.

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Table 1: Details of Study Sections

SI No	Name of the road	Type of road	Name of market area	Length of study section
1	Bakrahat road	2-lane (Rural highway)	Shamali Market area	2.5 km
2	Basanti Highway (SH3)	2-lane (Rural highway)	Ghusighata and Bamanpukur market area	4.8 km
3	MG Road	2-lane (Semi-urban Road)	Keorapukur Market area	2.4 km

All three study sections are of two-lane single carriageway standard and traffic is heterogeneous. Nature of side friction characteristics are also being similar, collected data have been compiled together to develop speed- flow graphs for a wider range. Field data were collected in morning market hours (6.00am-11.00am). The data were not collected for remaining part of the day as the characteristics of these sections of roadways remain same as that of the roadway sections without any roadside market activities. One set of representative traffic and friction data have been collected for each five-minute interval. Therefore, collected data is discrete type representing prevailing traffic and side friction condition for each five-minute time period.

### Traffic Data

Traffic volume count survey was carried in morning market hours (6.00AM to 11.00AM). It was found that hourly traffic volume varies among three study sections. High volume of traffic found on MG road while Basanti Highway having low traffic volume. Traffic compositions in three study stretches for a typical hourly traffic are shown in Fig.1. It was observed that traffic composition in three study sections is highly heterogeneous with good amount of slow moving vehicles. Variation of hourly traffic volume in three study sections is shown in Fig. 2.

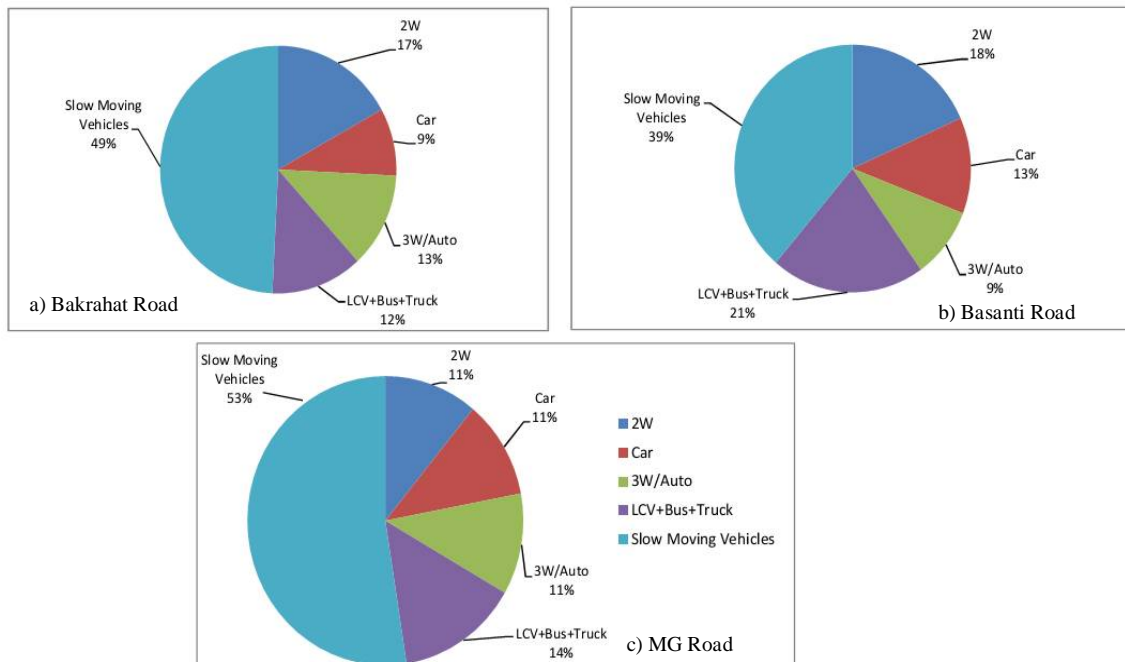


Fig. 1. Typical composition of traffic in three study sections

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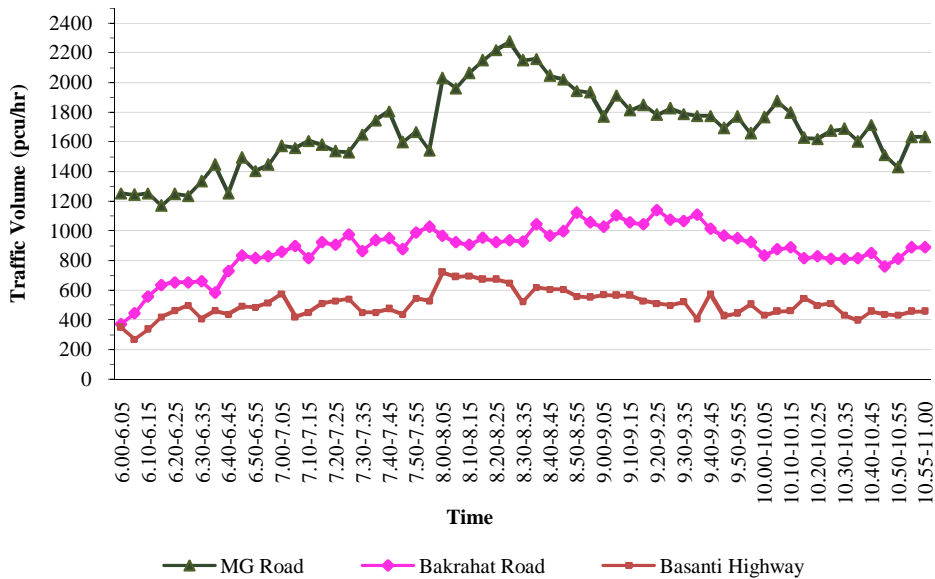


Fig. 2. Variation of hourly traffic volume in three study sections

### Speed Data

Two sets of spot speed data were collected using ‘Laser Gun’. One set of data collected within market area and another set of data collected outside the market area. For each five-minute interval three spot speed readings were obtained at random. Different vehicle types were targeted during speed data collection to represent heterogeneity in speed data. Representative stream speed was estimated using relationship between spot speed and stream speed.

### Quantification of side friction

Friction elements will have different impact on travel speed of through traffic depending on their physical dimension and position on carriageway. For example, a cycle on the middle of carriageway will certainly have more impact on through traffic speed in comparison with a pedestrian standing on carriageway edge. Similar to the concept of Passenger Car Unit (PCU) where the impact of passenger car on traffic flow is considered as unity, pedestrian standing on carriageway edge strip considered as unit of friction for the present study.

Focus area of the present paper is to study the impact of the side friction generated in roadside market areas. Pal and Roy (2016) [8] in their paper proposed a methodology to quantify the effect of side friction generated in road side markets. Five LOS were recommended considering operational speed and freedom of manoeuvre as measure of effectiveness. The concept of weight factor was developed to assign different weights to each friction element based on their contribution towards disturbance to through traffic. Weight factors were calculated considering the projected area of respective friction element and their distance from carriageway edge. It was observed during repeated field visits that a number of friction elements vary across the cross-section of the road in market areas. Number is more near carriageway edge, and it gradually decreases towards the centre of the carriageway.

An index namely ‘Road Side Friction Index (RSFI)’ is proposed to quantify the effect of side friction. RSFI for a particular instance is defined as a number of each type of friction element (pedestrian, cycle, rickshaw-van) standing or crossing the carriageway within a trap length of 100m multiplied by respective weight factor (Eq. 1).

$$\text{Road Side Friction Index, RSFI} = \sum w_i N_i \dots\dots\dots (\text{Eq.1})$$

Where,

$$N_i = \text{Number of } i^{\text{th}} \text{ type friction elements in 100m road stretch}$$

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$w_i$  = Weight factor for  $i^{\text{th}}$  type side friction parameter

## Road User Cost

Benefits of highway improvement are varied in nature, some of them are direct while others are indirect. Road User Cost is composed of following three components i) Vehicle Operating Cost, ii) Travel Time Cost and iii) Accident Cost. One of the direct benefits of road improvement is the reduction of Vehicle Operating Cost (VOC). IRC SP30-2009 [9] provides detail guideline for economic evaluation of highway projects. Research works carried out in India established the relationship of Road User Cost on following factors;

- i) Roadway Factors
  - a) Pavement width
  - b) Pavement surface type
  - c) Horizontal geometry
  - d) Vertical Profile
  - e) Number of junction per km
- ii) Vehicle Factors
  - a) Type
  - b) Pavement surface type
  - c) Horizontal geometry
  - d) Vertical Profile
  - e) Number of junction per km
- iii) Traffic Factors
  - a) Traffic volumes
  - b) Traffic composition
  - c) Speed
  - d) Congestion

Considering the findings of research work carried out in India Vehicle Operating Cost (VOC) components are Fuel and Lubricants, Tyre and Spare parts, Wages of crew, depreciation and overhead cost. Exhaustive tables are provided in IRC SP30-2009 for VOC calculation for various types of vehicles.

In present study focus area is impact of side friction generated from road side markets on performance of rural highways. Fast moving vehicles interact with friction elements within market area in a very random manner. Frequent deceleration/acceleration occurred during passing such market areas. In the present work following two components were selected to demonstrate impact of side friction Road User Cost.

- i) Fuel Consumption (FC)
- ii) Value of Passenger Time/Commodity value (for commercial vehicles)

Other components like Spare Parts Cost, Crew Cost, Fixed Cost, and Depreciation Cost considered to be independent of side friction.

In case of commercial vehicle, an important component of Road User Cost is the value of commodity in transit. Depending on commodity type these values may vary widely. If travel speed is high it implies that for transporting the same quantity of goods in a certain distance and period, less number of commercial vehicles can be used. Quicker travel also results in time savings to the vehicle crew. Value of commodity in transit may be considered separately for different types of commercial vehicles plying on primary and secondary routes. A detailed research work having title 'Updation of Road User Cost Data' was conducted by CRRRI in 2001 [10] in India by considering WPI price level as on 21.03.2009. These values may be updated based on current WPI value. However, for the present study, typical equations as recommended in SP-30 for VOC and CF were used to demonstrate impact of side friction on Road User Cost.

Typical VOC equations as recommended in IRC SP-30-2009 for private car and Trucks for selected two components are furnished below;

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## Private Car:

- i) Fuel Consumption  
 $FC = 21.85 + (504.15/V) + 0.004957V^2 + 0.000652*RG + 1.0684*RS - 0.3684*FL$
- ii) Value of Passenger Time (for Primary Routes)  
 $PT_{TR} = 227.82/V$

## Trucks (2-Axle):

- i) Fuel Consumption  
 $FC = 44.08 + (3904.64/V) + 0.0207*V^2 + 0.0012*RG + 3.3281*RS - 1.7769*FL$
- ii) Value of commodity  
 $CMV_{TR} = 151.91/UPD$   
Where, UPD = Utilisation =  $28.773 + 2.181*V$

## Two Wheelers:

- i) Fuel Consumption  
 $FC = 3.38 + (549.57/V) + 0.00436*V^2 + 0.000196*RG + 0.4552*RS - 0.3386*FL$
- ii) Value of Passenger Time (for Primary Routes)  
 $PT_{TR} = 45.1/V$

Where,

FC=Fuel consumption in cc/km

V=Speed in km/hr

RG=Roughness in mm/km

RS=Rise in m/km

FL=Fall in m/km

$PT_{TR}$ = Value of passenger time in trunk route in Rs/km

$CMV_{TR}$ = Value of commodity on trunk route in Rs/km

## IV. IMPACT OF SIDE FRICTION

### Impact on travel speed

Speed data obtained from three study sections were compiled together and cumulative speed distribution curve was developed. It is observed from cumulative speed distribution curve (Fig.3) that 85<sup>th</sup> percentile speed (operational speed) for outside market and within market scenario are 50 km/hr and 25 km/hr respectively. Substantial (50%) reduction occurs in operational speed within the market area due to the presence of side friction. It is also observed from the curve that speed range is wider in case of outside market area. This is because of reduction in overtaking opportunity in market areas.

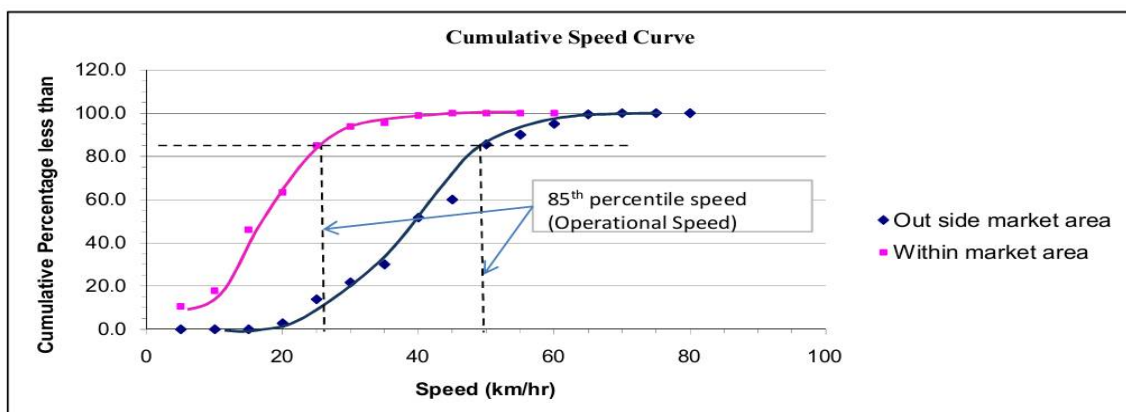


Fig. 3. Cumulative speed distribution curve



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Percentage reduction of operational speed in individual study section is shown in Table 2. It is observed that speed reduction is less in case of MG road as prevailing speed is already reduced due to high traffic volume.

Table 2 Details of operational speed in three study sections

Study sections	85 <sup>th</sup> Percentile speed (operational speed)		Percentage reduction of operational speed
	Outside market	Within market	
	(km/hr)	(km/hr)	
Bakrahat road	55.0	30.0	45.5%
Basanti road	50.0	25.0	50.0%
MG road	32.0	23.0	28.1%

Statistical analysis carried out using combined speed data collected from three study sections. Standard statistical parameters like Average speed, Median, Standard deviation and Variance were calculated for both outside and within market area scenario. Results are shown in Table 3. It is observed that values of all statistical parameters that represent a range of variation within data set are lower for within market scenario. It indicates that freedom of overtaking and maneuvering opportunity is restricted within the market area.

Table 3 Statistical parameter for speed data

Statistical parameter for speed data	Outside market			Within market		
	Bakrahat Road	Basanti Highway	MG Road	Bakrahat Road	Basanti Highway	MG Road
AVERAGE	47.70	43.53	27.64	20.03	21.92	9.15
MEDIAN	45.82	42.14	26.41	17.49	21.49	9.28
STDEV	8.91	6.60	5.57	8.34	5.32	4.94
VAR	79.38	43.52	31.06	69.48	28.33	24.38

In normal condition, the stream speed reduces with increase in traffic volume. In the present work this characteristic is well prevailed in the roadway section outside the market area. In this area speed reduction has been measured with respect to observed Free Flow Speed (FFS) and expressed as Percentage Speed Reduction (PSR). Relationship between PSR and V/C ratio has been developed and shown in Fig. 5.1. It was observed that rate of speed reduction was higher for lower V/C values as manoeuvring opportunity starts decreasing rapidly as traffic volume increases. Beyond certain traffic volume (V/C=0.3) further increase of traffic volume will cause speed reduction at lower rate because of flow approaching a saturated state.

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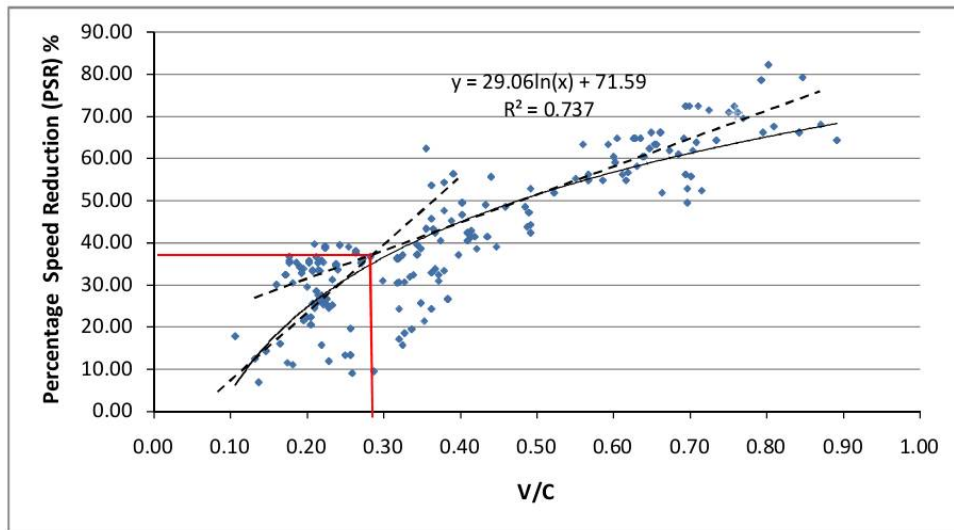


Fig. 4. Relationship between PSR and V/C

As vehicles enter into market area, travel speed is further reduced due to presence of friction elements. In this scenario, Percentage Speed Reduction (PSR) has been measured with respect to prevailing speed in outside market area. Prevailing side friction is expressed as Road Side Friction Index (RSFI). Relationship between percentage reductions of speed and RSFI is shown in Fig. 5. PSR calculated for within market area scenario represents exclusive speed reduction for side friction.

It was observed that rate of speed reduction is higher for lower RSFI values as manoeuvring opportunity starts decreasing rapidly as side friction increases. Beyond certain level (RSFI=50), further increase of side friction will cause speed reduction at lower rate. This is because of fast moving vehicle within market area already lost mobility and opportunity for overtaking reduced substantially.

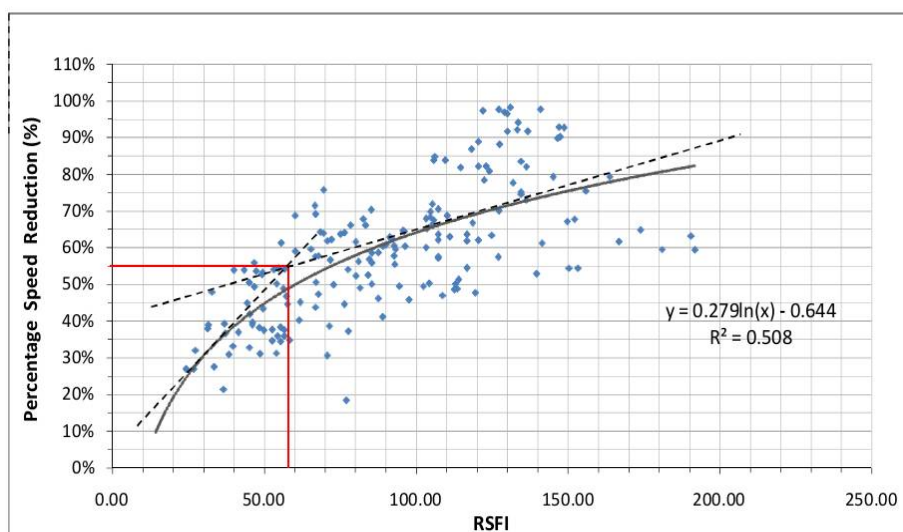


Fig. 5. Relationship between PSR and RSFI



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## Impact on Road User Cost

In recent past many researchers tried to investigate impact of average speed, stopping, acceleration/deceleration on fuel consumption, CO, NOx emission etc. At signalized intersections, vehicles decelerate, stop, queue up (during red signal) and then accelerate during green and amber signal. The way vehicles decelerate, stop, crawl in queue, and accelerate to leave the intersection depends on number of factors such as, individual vehicle type, driver behaviour, number and type of vehicles at intersection etc.

First moving vehicles decelerate while interacting with friction elements or following the slow moving vehicle ahead. In scenario when traffic volume and side friction level both are high, platoon used to form and through traffic compelled to travel in crawling speed.

### Congestion Factor (CF)

In developing countries like India traffic is highly heterogeneous. With the increase in traffic volume, manoeuvring opportunity for fast moving vehicles decreases. The Fast moving vehicles need to accelerate/ decelerate repeatedly to overtake or negotiate slow moving vehicles. This manoeuvres result in drop in speeds and increase in fuel consumption along with wear and tear of vehicles. As per IRC SP30-2009 guideline the congestion effect on VOC dealt separately for distance-related and time related components.

Presence of friction elements within market areas makes the scenario more complex in nature. In addition to interaction among various types of vehicles, random interaction occurred between vehicles and friction elements. In these market areas not only speed of the vehicles reduces substantially but also driver needs to accelerate/decelerate continuously while interacting randomly with friction elements.

In common practice this effect is considered as 'Congestion effect' while estimating Vehicle Operating Cost. A multiplying 'Congestion Factor (CF)' is used to accommodate impact of interaction among various type of vehicles. Values of CF directly depend on Volume to Capacity Ratio (VCR) as per IRC SP 30 guideline. Equations recommended in IRC SP-30-2009 for estimating Congestion Factors are shown in Table-4.

Table 4 Details of Congestion Factor (CF) equations as per IRC SP 30-2009

Vehicle type	Fuel Consumption	Passenger Travel Time	Commodity Value
Car	$0.893+0.259*VCR$	$1.087+0.483*VCR$	-
Truck	$0.925+0.482*VCR$	-	$0.878+0.561*VCR$
Two Wheeler	$0.917+0.112*VCR$	$0.804+0.865*VCR$	-

Traffic congestion on roads varies substantially within a day. Above congestion factors needs to be corrected for peak hour factors. IRC SP-30-2009 recommends a multiplying factor of 0.8 with the CF derived from above equation for accommodating peak hour factors.

In the present study side friction levels have been categorized into five levels i.e. very low, low, medium, high and severe based on prevailing value of Road Side Friction Index (RSFI). Speed flow curves were developed for various side friction levels and corresponding capacity values were estimated. It was observed that for a constant traffic volume, value of Congestion Factor increases with increase of side friction level. This is because of substantial decrease in capacity value of the road section with the increase of side friction level resulting increase in Volume Capacity Ratio. Corrected CF values were used while estimating various VOC components.

### Impact on RUC components

With the increase in traffic volume, manoeuvring opportunity for fast moving vehicles decreases. Fast moving vehicles compelled to follow slow moving vehicle ahead for a short period of time while searching for opportunity for overtaking. In the process, driver needs to accelerate and decelerate the vehicle several times. Within market area fast moving vehicles interact with friction element in very random manner. Repeated acceleration and deceleration results in high fuel consumption. Per km fuel consumption for a single vehicle of different types i.e. car, two wheeler and truck were calculated using VOC equations for various side friction levels. Results are plotted below in Fig. 6.

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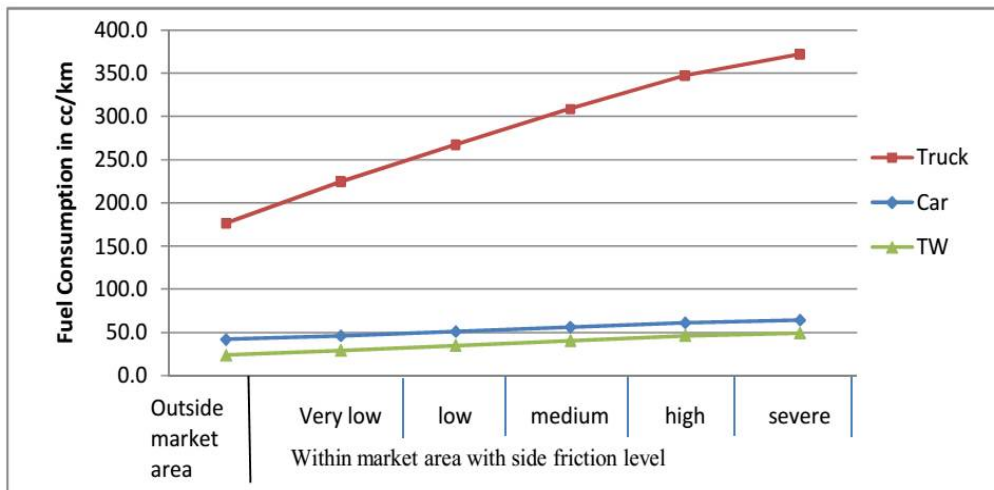


Fig. 6 Variation of fuel consumption for different type of vehicles

It was observed that fuel consumption increased substantially when side friction level is medium to severe. Impact of side friction on fuel consumption is considerably high in case of heavy vehicles. Values of passenger travel time depend on importance of route, purpose of travel and other socio economic conditions. In present work, values of passenger travel time were calculated using VOC equations provided in IRC SP30-2009 for Indian condition. Results are plotted in the Fig.7. It was observed that cost of per km travel time increases substantially due to side friction in case of private car. However, in case of two wheelers effect is not significant. Variation of per km commodity value in case of commercial vehicles for different side friction levels is shown in Fig.8.

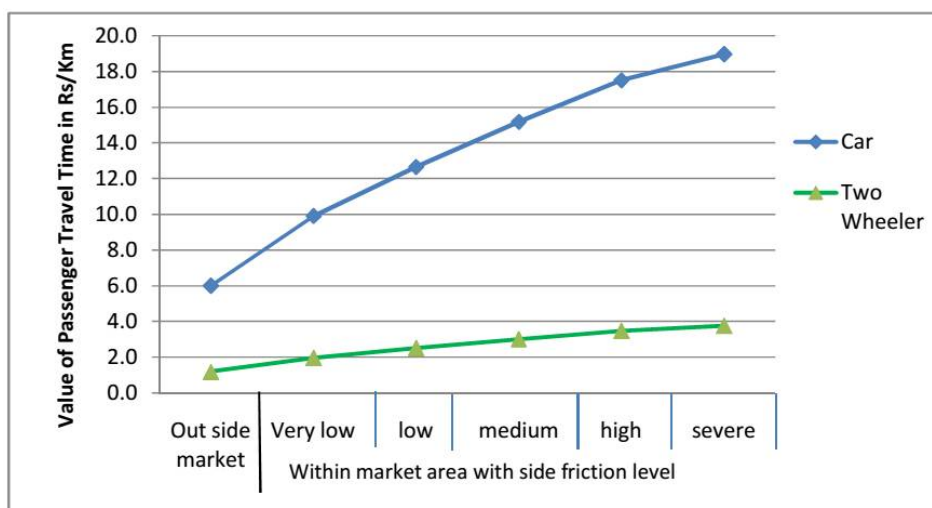


Fig. 7 Variation of passenger travel time

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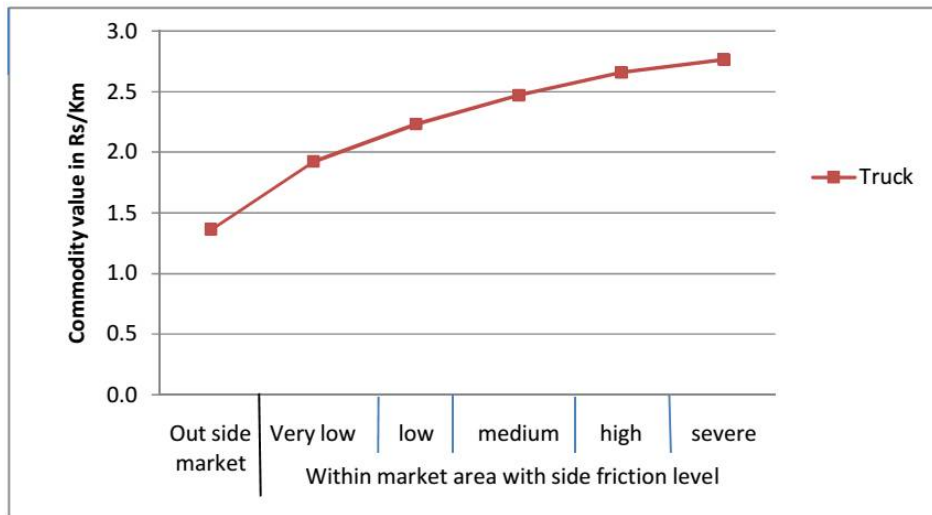


Fig. 8 Variation of commodity value for trucks

### Impact on RUC of a homogeneous section

To demonstrate impact of side friction on Vehicle Operating Cost (VOC) for a typical homogeneous section, 40 km length of Basanti road was selected. Within this homogeneous section sixteen road side markets exist with various side friction levels. Speed within market area was estimated using relationship established in the present study between PSR and RSFI.

Additional cost for fuel consumption, cost of passenger travel time and commodity values were estimated for unit km road length using VOC equations comparing outside and within market area scenario with respective side friction levels. These values were multiplied by the respective length of markets to obtain additional cost incurred by the vehicle/passenger while travelling through these market areas. Unit cost of diesel and petrol were considered as Rs 58/- per lit and Rs 70/- per litre respectively. Though traffic survey revealed that various types of motorized and non-motorized vehicles were travelling on the road, for demonstration of additional road user cost, three types of vehicles i.e car, truck and two wheelers were considered.

Number of private car, truck and two wheelers as obtained from Average Daily Traffic (ADT) volume were respectively 823, 931 and 1813 respectively. Occupancy factor for car and two wheeler are considered as 4.8 and 1.5 respectively. Total road user cost considering selected three major components i.e. cost of fuel, travel time and commodity incurred by trucks, cars and two wheelers were estimated for two scenarios.

In the first scenario, no road side markets were considered. A typical medium level traffic volume (1000 pcu/hr) was considered for entire stretch and fuel consumption, travel time and commodity value were estimated. Similarly, road user cost was estimated for with market scenario considering sixteen road side markets in 40km length of homogeneous section. Same traffic volume (1000 pcu/hr) was considered for entire stretch. Fuel consumption, travel time and commodity value estimated as per IRC SP-30 VOC equations. Length and side friction level of each market considered separately and sum up to obtain RUC for entire section. Total length of sixteen markets is 9.4km and remaining 30.6km length fall under without market category. It was observed that road user cost was increased substantially due to presence of side friction. Details of component wise increase of per km road user cost for different types of vehicles for travelling 40km of study section has been shown in Table 5.

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Table 5 Percentage increase of various RUC components

Vehicle type	Fuel Cost (Rs/km)		Percent increase	Value of travel time/commodity (Rs/km)		Percentage increase	Total RUC (Rs/km)		Percent increase
	Without market	With market		Without market	With market		Without market	With market	
Private Car	2.97	3.741	26.1%	27.34	40.89	49.6%	30.31	44.63	47.3%
Truck	10.14	14.532	43.3%	1.31	1.61	22.8%	11.45	16.14	41.0%
Two-Wheeler	1.69	2.304	36.6%	1.69	2.15	27.3%	3.38	4.89	44.6%

Comparison of per/km RUC incurred by different type of vehicles for with and without market scenario is shown in Fig. 9.

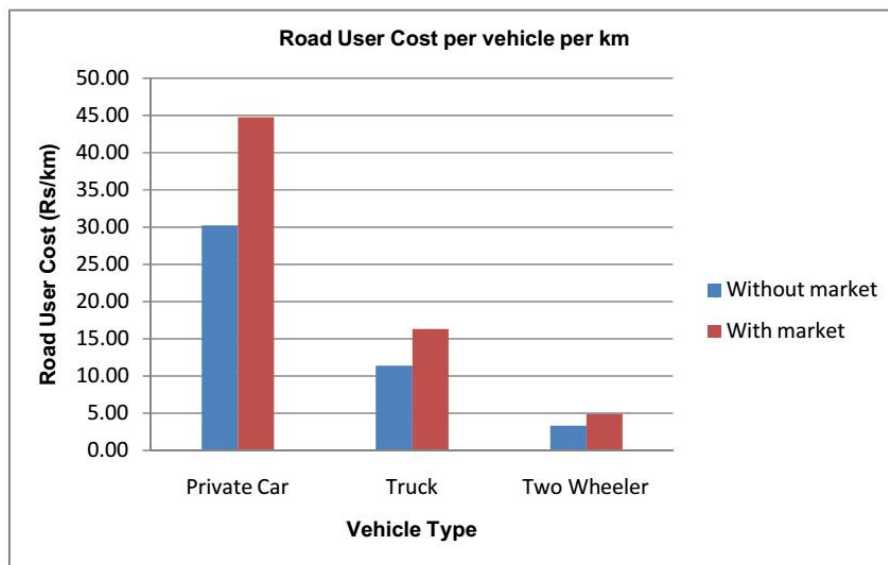


Fig. 9 Comparison of road user cost for with and without market area scenario

## V. CONCLUSION

In the present paper a methodology has been proposed for quantification of impact of side friction generated from road side markets on performance of two-lane rural roads. A Road Side Friction Index (RSFI) is developed to quantify the side friction and its relationship with travel speed has been demonstrated. It is demonstrated that road user cost incurred by different vehicles increased substantially while travelling through a road section having road side market areas in between. This additional amount is not directly paid by the road user but indirectly incurred by them due to presence of road side markets with various side friction levels along the sections. This additional cost is not only loss to individual road users but also huge loss of society at large. Typical example has been demonstrated with the help of 40km study section considering three types of vehicles only. Thousands of such road side markets exist along almost all national/state highways of developing countries like India. Presence of this side friction also restricts the benefit of investment in road infrastructure for improvement in level of service of road section. Findings of the study would certainly justify the implementation of policy measures to keep away such market activities from the carriageway.

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