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Analysis of naturalistic driving behavior under heterogeneous traffic conditions in India

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Abstract

This study aims at understanding the drivers' responses to various geometric and traffic parameters on a selected road network. The study stretch comprising of rural and suburban traffic was selected to observe the variability in driver's behavior. The naturalistic driving data for various drivers was collected using high-end GPS data loggers with the device fixed inside the heavy motor vehicles. The subject vehicle drivers' responses to different events such as intersections, mid-block openings and lead vehicle were recorded over a stretch of 23 km for 92 trips resulting in 69 hours of driving data. The analysis results revealed that, without crossing vehicles at intersections and mid-block openings, the drivers did not respond to geometric elements. However, for intersections and mid-block openings with crossing vehicles, the drivers were found to reduce the speeds by 12.99 and 15.28 km/h respectively. For lead vehicles, the drivers were responding only when the subject vehicle is at a distance of 18 m in rural area and 9 m, in the suburban region. Of all the events, 85% of the time, the drivers were found to respond to the lead vehicles when the subject vehicle speeds were higher than 53.55 km/h in rural area and 36.35 km/h in sub-urban area. Moreover, the subject vehicle's response to the lead vehicle was found to be dependent on the lead vehicle's speed.

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Keywords: Driver behavior; Naturalistic driving data; Mixed traffic; Responses.

1. Introduction

According to the World Health Organization (WHO), traffic injuries are a leading cause of death resulting in 1.25 million deaths every year on the roads. In low & middle-income countries, this loss of lives is consequently resulting in economic losses of up to 5% GDP (WHO, 2015). Indian Ministry of Road Transport and Highways (MoRTH) reported that 77.1% of total road accidents in 2015 are caused due to the fault of the driver, whereas in 2016 it increased to 84%. The accident inducing factors concerning driver are of major interest to researchers to incorporate recent

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technologies in the system and to inform and guide drivers for safe travel.

Driver behavior is very complex to understand and generalize. Earlier research on driver's behavior was with self-reported surveys, demographic profiles, and risk perceptions. The reliability of this sort of data is minimal, as the perceptions and reactions of drivers are not captured in a realistic manner but on a judgmental basis. So, the study of the naturalistic driving behavior of several road users is highly demanded, where the realistic performance of drivers in day-to-day driving operations can be captured continuously on various road sections. Some advanced instruments are used as a part of naturalistic behavior studies which identifies driving attributes.

However, the effect of heterogeneous traffic conditions and violations in lane discipline on driving behaviors is not yet well addressed. These are the common events that can be observed in Indian road traffic conditions. And also, the change in the driver's behavior concerning urban and rural traffic patterns is an important aspect which needs further research. So, the study of the naturalistic driving behavior of several road users for Indian road traffic conditions is highly needed to understand how a driver reacts and responds to the surrounding situations. This study aims at understanding the variations in driver's responses to geometric and traffic parameters in rural and suburban regions. We have collected data for heavy motor vehicles over 23km road stretch comprising rural (11 km) and suburban (12 km) regions. The data was collected using high-end GPS data loggers along with two-video cameras. The observed parameters are approach speeds near intersections and mid-block openings, maximum speeds before responding to the lead vehicles, anticipating distances at the time of response and deceleration variations. These parameters are extracted and compared for rural and suburban traffic conditions. The variations distinguished in this study will be highly useful in developing speed reduction models, predicting driver's responses and identifying aggressive drivers. This paper mainly presents a descriptive analysis of the driver's responses to different events.

The paper is segmented into *five* sections including this section. The brief literature on driver behavior analysis is discussed in *section two*. The details of data collection and extraction procedures are presented in the *third* section. Analysis of behaviors and variation in responses concerning rural and suburban traffic conditions is presented in section *Four*. Finally, the summary of the study is presented in section *five*.

2. Literature review

It is a known fact that any parameter with human involvement is complex to analyze, as the behavior is a result of various events & situations. To understand the naturalistic driver behavior of drivers the continuous monitoring of driver's decisions is required. The 100-car Naturalistic driving study (Neale et al., 2005) is one among the major studies to date with a detailed database regarding driver behavior & performance under various traffic situations and environment. Various in-vehicle devices, sensors, and video channels were installed in 100 cars over 12 months. Dingus et al., (2006) classified this data into incidents and formulated an event database which presents various vehicle to vehicle interactions along with video and vehicle performance data. Toledo et al., (2008) conducted a similar study on 191 pickup trucks to evaluate the driver behavior and report on the effect of In-vehicle data recorders (IVDR) installation and feedback on crash rates. Risk indices based on speed and acceleration behaviors were calculated for the individual driver and the trip as well. The feedback was reported to the drivers during the study period (seven months) and observed a significant reduction of 38% in crash rates. Guo and Fang (2011) studied the factors associated with risky driving and developed models to predict high-risk drivers based on near-crash and crash rates. Ellison et al., (2015) formulated a different framework to determine risk indices, introducing the concept of temporal and spatial identifiers (TSI) which incorporates the effect of space and time on the driver's behavior. Authors used the speed curves developed by Kloeden et al., (1997) using accident reconstruction techniques, to determine the respective risk of getting into an accident.

Modeling and understanding these behaviors under various traffic conditions is very much needed for effective traffic management & control and also for developing driver assistance systems. Earlier, driving behavior models were focused on longitudinal interactions of vehicles, termed as car-following models. Pipes (1953) introduced the concept of 'law of separation' and studied the dynamics of motion of lead vehicles. Later the emergence of microscopic simulation models led to the introduction of acceleration and lane-changing models (Gipps1986). Schorr et al., (2014) designed an instrumented vehicle to capture the trajectory data and studied the impact of road geometry on driving behavior. Authors used the data to calibrate the parameters of car-following model and identified significant changes in driver's behavior concerning specific road infrastructure elements. Hill et al., (2014) studied the relation between freeway lane changing and the driver performing the maneuver. In this study, an instrumented vehicle was driven by forty-six participants resulting in a total of 726 lane changes. Authors suggested that the type of driver should be taken into consideration while developing simulation-based lane-changing models for freeways. The interdependencies of driving decisions were not addressed in these models. Toledo et al., (2007) introduced a concept of short-term goal and short-term plan to formulate integrated driving behavior model, which captures the interdependencies among various decisions. The data was collected at specific sections where the direction of traffic movements tends to change, which helps in understanding correlations among driver's decisions. A few research groups are working on driver behavior in India. Chakrabarty and Gupta (2013) studied the psychomotor and driving behaviors during adverse weather conditions. Behaviors under simulated conditions were observed using Zen car driving simulator, and Field Surveys were conducted on twenty-one drivers over 21-days with the help of V-Box and three cameras. This study highlighted the pattern of crashes and state of drivers during foggy and rain conditions. A pilot study (2014) was initiated by Central Road Research Institute (CRRI) on goods vehicle drivers from a single largest company, to understand the psychological traits and safety skills. Chakrabarty and Riku (2013) studied the aggressive behaviors of Indian drivers based on traffic violations and risky behaviors (like red light running and wrong side overtaking), and some mitigation measures are recommended and initiated by CRRI. Pawar and Patil (2018) studied the behaviors of major road vehicles at un-signalized intersections when the minor road vehicles exhibit aggressive maneuvers. The driving simulator was used to test 51 drivers over nine un-signalized intersections for four conflicting events. This study also investigated the effects of the handheld phone on driving performance. Chakroborty and Agarwal (2004) developed a comprehensive microscopic model to describe driver behaviors in uninterrupted traffic flow conditions. Simulated driving behavior for 19 driving scenarios is used for validating the model, but the stop-and-go and near-capacity traffic conditions are not incorporated in this study.

The previous researches on driver behavior and modeling were more on specific vehicular fleets, driving conditions and road environment. So, to understand the complexity of the driving task and the factors affecting the driver behavior for Indian road traffic conditions, it is important to study the variations in driving behaviors concerning geometric and traffic parameters.

3. Data collection and extraction

Although the driver's behavior is a result of many situations and circumstances, the geometric design is considered to be one of the major influencing factors. A study section of 23 kilometers is selected on the four-lane divided national highway (NH-65) near Hyderabad city, which consists of 12 intersections, 13 mid-block openings, and four gentle curves. The stretch is divided into rural and sub-urban categories based on the surrounding developments, geographical position and traffic characteristics.

Data collection process started in May 2018 and continued for five weeks, ensuring the weather is clear and dry. The data is collected for 92 trips (five drivers) comprising of 69 travel hours over 2116 kilometers. The drivers are professional with the driving experience of more than five years and employed as drivers. All the subjects were informed about the objectives of the study and instructed to drive in their natural way. The drivers were assured of no actions against them, as the results of the study are exclusively for research.

3.1 Data collection

The naturalistic data is collected for heavy motor vehicles using GPS data loggers and two-video cameras, at a sampling rate of 10 Hz. The instrument is mounted in the vehicle before the start of each trip and monitored by the research team. The heavy passenger vehicles used for the study and the camera positions in the vehicle are depicted in Figure 1. One camera is fixed on the windscreen to capture different events and the lead vehicles' movements. The second camera is fixed on the left side of the vehicle focusing rear side, to capture the effect of overtaking vehicles on the subject vehicle (rear side view). In India, the HMV's are found to ply on the innermost lane (i.e., lane close to the divider) to avoid friction due to vulnerable road users such as bicycles, two-wheelers, and auto rickshaws. The instrument records video data along with continuous positional coordinates of the vehicle. This data is stored in a memory card and is retrieved once after four trips.

Fig. 1. (a) & (b) Study vehicles used for data collection; (c) & (d) camera positions to record video data.

The trips are planned carefully to capture the behavioral variations with changing traffic patterns in the suburban region. So, the study period is divided into four segments based on traffic demand, as shown in Table 1. The first and fourth periods are corresponding to peak hours whereas the second and third periods are during off-peak hours. Data collected during morning and evening peak hours constitute 71% of total data, ensuring a significant number of vehicles to vehicle interaction events.

Table 1. Trip distribution details in various time segments.

Period (am/pm)	Number of hours	Percentage
8.00 am to 11.00 am	22.5	32.61
11.30 am to 2.30 pm	12.75	18.48
2.30 pm to 5.30 pm	6.75	9.78
5.30 pm to 8.30 pm	27	39.13
Total	69	100

3.2 Data extraction

The Data extraction process is divided into five stages.

- Identification of geometrical features based on reference longitudes and latitudes (intersections and mid-block openings)
- Extracting driving performance data (responses) at different geometric elements such as intersections and midblock openings.
- Identifying the instances (based on video) when the subject vehicle encounters the surrounding traffic and extracting related driving performance data.
- Manual observation of selected instances from the forward and rear side view camera, to categorize the instances, such as responding to the lead vehicle, (or) to the overtaking vehicle, (or) to the unexpected lead vehicle maneuver.

The analysis results presented in this study comprise 15% of the total data collected. Moreover, the data used in the study is substantial to arrive at a certain conclusion. The extracted parameters are abbreviated in Figure 2 (i and ii). For intersections and mid-block openings, the approach speed of the subject vehicle at the center of intersection (or) mid-block opening (1. V_0) and 75 meters before the intersection (2. V_{75}) area are extracted. The distance 75 meters was selected based on the previous study recommendations (Pawar and Patil, 2014, 2018). Also, in the current study, it was observed that the drivers respond to the geometric elements such as intersections and midblock openings when at the distance of 60 to 80 meters. In addition to the speed data, the maximum deceleration over 75 m length, the presence of lead vehicle (3. Lead vehicle [Yes / No]), crossing vehicle (or) turning vehicle (4. Crossing vehicle [Yes / No]), and observed friction from the other vehicles (5) were extracted. When the subject vehicle is responding to the surrounding traffic, the clear distance to the lead vehicle (a) based on road markings, the initial response speed of the subject vehicle (b. $V_{Initial}$), and the extent of speed reduction and maximum deceleration (d) during the maneuver were extracted. The cause for the deceleration was noted manually by observing the recorded videos.

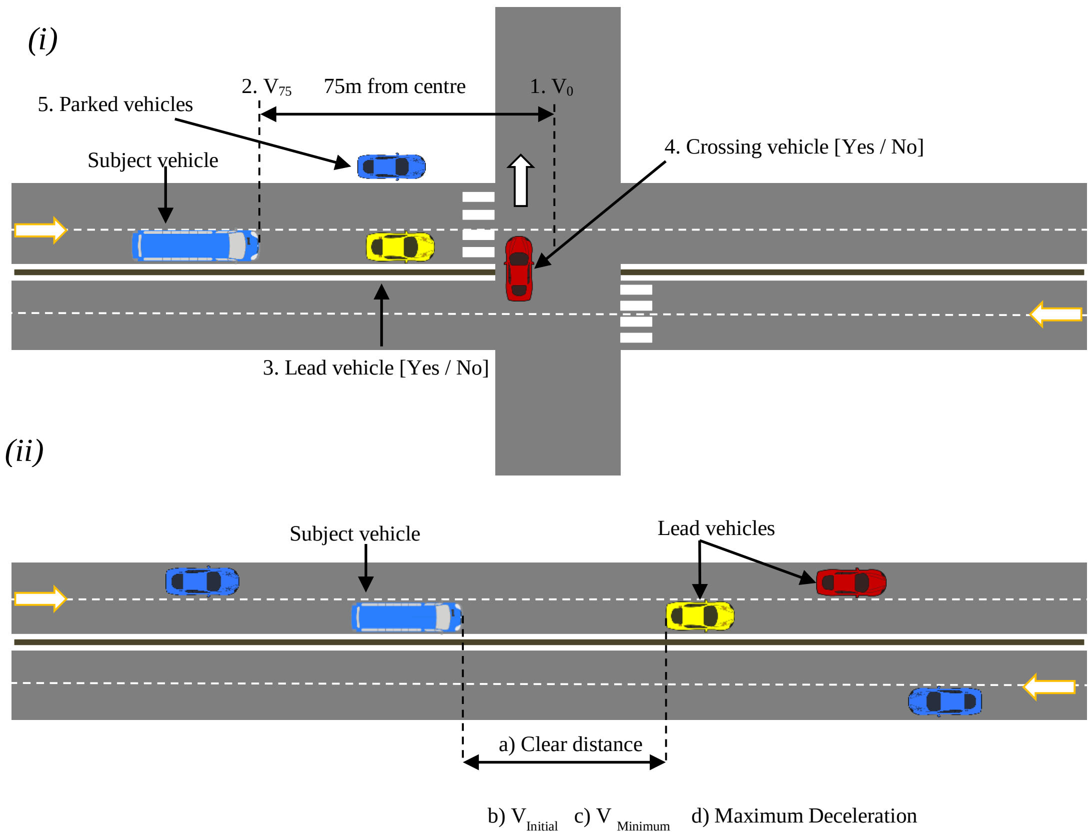

Fig. 2. Parameters extracted (i) when the subject vehicle is approaching an intersection (or) mid- block opening; (ii) When the subject vehicle is responding to the lead vehicle.

4. Analysis of behavioral parameters

The average velocity and travel time observed for rural and sub-urban regions during peak and off-peak hours are presented in Table 2. The average velocity on a rural highway is found to be higher than the suburban counterpart by 10 km/h. The consistent travel time values in the rural region speak of least disruption from the traffic. Whereas in the suburban region, evening peak hour trips were found to exhibit more travel time due to heavy traffic interruptions.

Table 2. Average velocity and travel time details during peak and off-peak hours.

Time Segment	Rural (11 km)		Sub-Urban (12 km)	
	Average Velocity (km/h)	Travel Time (min)	Average Velocity (km/h)	Travel Time (min)
Morning peak hours (8.00 am to 11.00 am)	52.86	11.97	39.57	19.54
Off-peak hours (11.30 am to 5.30 pm)	53.10	11.76	40.51	19.03
Evening peak hours (5.30 pm to 8.30 pm)	52.14	12.01	31.25	24.57

4.1 Intersections and mid-block openings

Road geometrical features are one among the major influencing factors on driver's behavior. Especially, intersections and mid-block openings are primary elements, which result in lateral disruption to the road traffic flow. The responses of drivers to these geometric elements are found to be dependent on many other situations such as the presence of lead vehicles, crossing vehicles, overtaking vehicles and roadside parked vehicles near the intersection. The speed choices and the speed reduction values pertaining to few events are presented in Table 3. The presence of crossing vehicle is observed to be major element which influences approaching drivers' speed choices. Of the total observations at intersections, 53% are noticed with the presence of crossing vehicle. Whereas in case of mid-block openings, 60% are observed with the presence of turning vehicles. For the instances with no crossing or turning vehicles the subject vehicle drivers were found not responding to these geometric features. The mean speed reduction (over the 75m stretch from intersection) with the presence of crossing (or) turning vehicles at intersections and mid-block openings is found to be 12.99 km/h and 15.28 km/h respectively with mean maximum deceleration (over the 75m stretch) of 2.8 m/s^2. The 85^{th} percentile deceleration values ranged from 1.9 m/s^2 to 4.3 m/s^2 for different events. The maximum deceleration value was observed when there is a crossing vehicle at the intersection area.

Table 3. Speed details at intersections and mid-block openings.

Criteria	Total %	85^{th} % approach speed (km/h) At 75m	Mean speed reduction (km/h)	Mean deceleration (m/s^2)	85^{th} Percentile deceleration (m/s^2)
Intersections with the presence of crossing vehicles	53	55.32	12.99	2.8	4.3
Intersections without the presence of crossing vehicles	47	57.37	0.68	1.0	1.9
Mid-block openings with the presence of turning vehicles	60	53.72	15.28	2.9	3.8
Mid-block openings without the presence of turning vehicles	40	54.38	0.80	1.1	1.9

The speed variation near intersections in the rural and sub-urban region is presented in Figure 3. The 15^{th} percentile approach speeds at 75 m from the center of the intersection are found to be 51.8 km/h in rural and 28.14 km/h in sub-urban regions. The mean approach speeds at 75 m from intersection are observed to be 54.84 km/h and 41.46 km/h in rural and sub-urban regions respectively. The approach speeds in sub-urban regions are lesser due to disruption from the surrounding traffic (refer to Table 2). And also, the speed reduction is more in case of the sub-urban region due to interrupting traffic near the intersections.

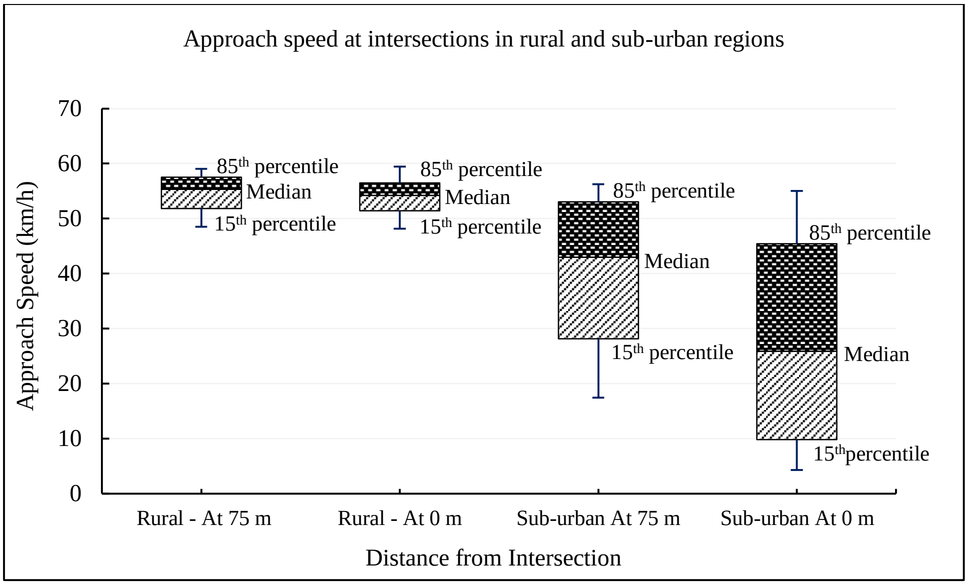

Fig. 3. Speed variations at intersections in rural and sub-urban regions

The typical speed profiles for a subject vehicle when approaching intersection and mid-block opening are shown in Figure 4 (a), (b), (c) and (d).

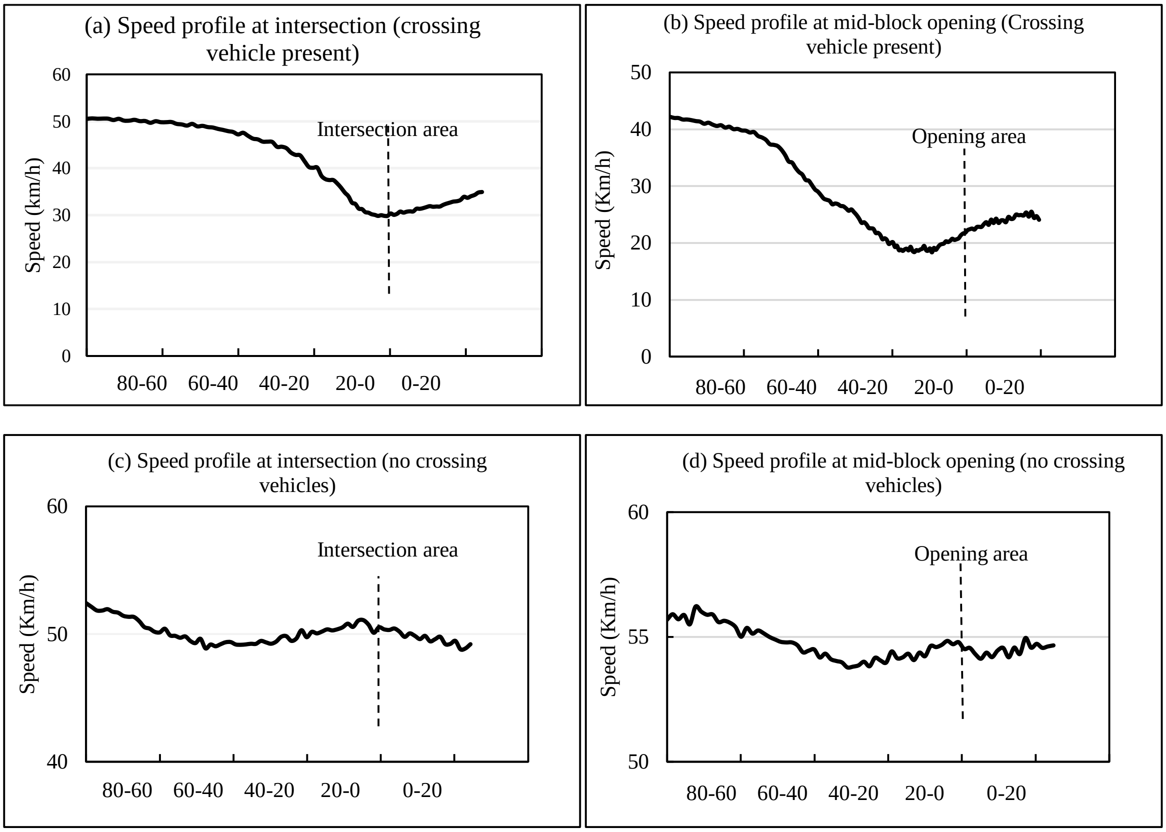

Fig. 4. (a), (b), (c) & (d). Typical speed profiles at intersection and mid-block opening.

The corresponding deceleration profiles at intersection and mid-block opening in the presence of crossing vehicle are shown in Figure 5 (a) and (b).

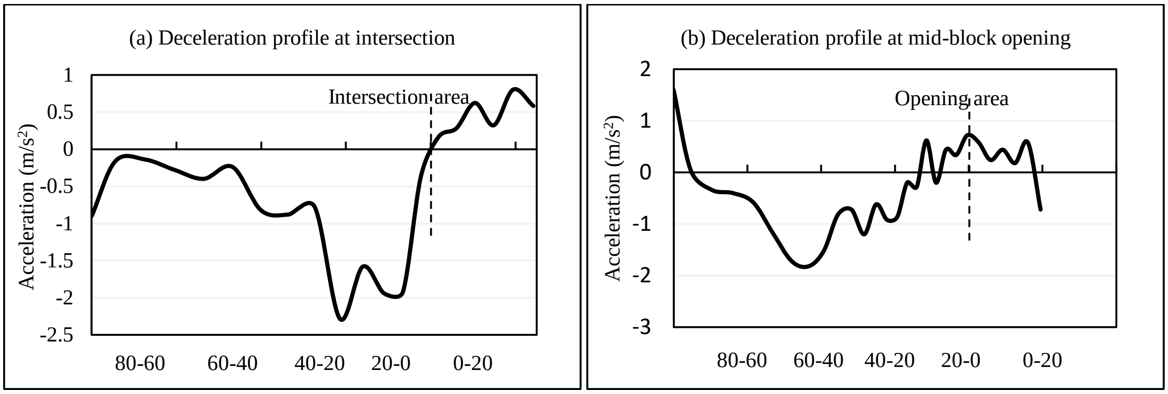

Fig.5. (a) and (b). Typical deceleration profiles at intersection and mid-block opening.

4.2 Response to lead vehicles

Over the midblock sections, the speed selection of drivers majorly depends on the available clear distance ahead to traverse at each instant. In this study, we recorded the speed and distance from lead vehicle at which the subject vehicle drivers reacted. The driver's response to the lead vehicle was recorded at the moment when subject vehicle driver responded by applying the brakes. The distribution of these events based on maximum deceleration is presented in Figure 6.

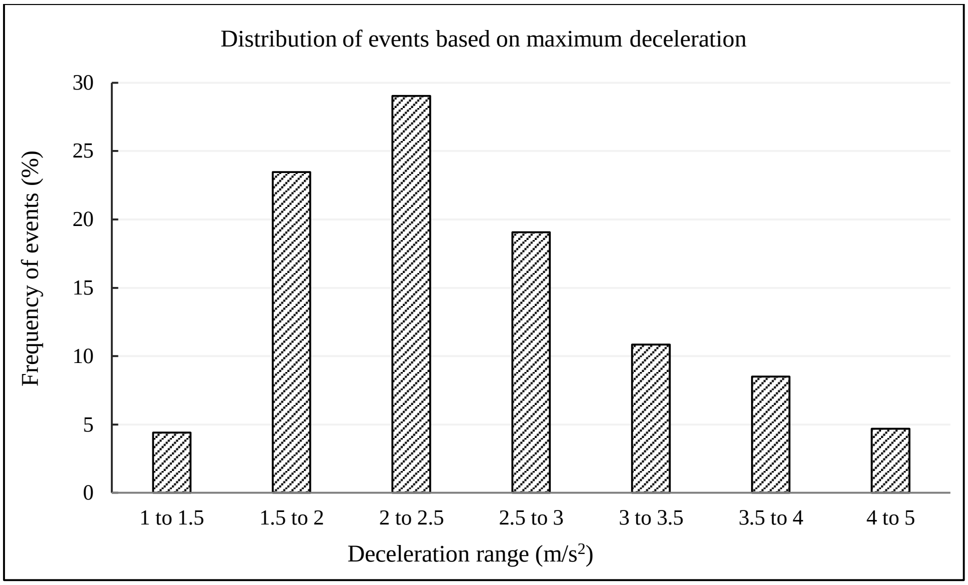

Fig. 6. Frequency distribution of events based on deceleration

In addition to the maximum value of deceleration, we extracted the corresponding initial speed during response and distance to the lead vehicle. The variation in speed and distance at the instant of response in rural and sub-urban regions are shown in Figure 7. For 85 % of time the drivers are found responding to the lead vehicle if the distance from the lead vehicle is equal to or less than 18 meters and the speed of subject vehicle is equal to or less than 53.55

km/h for rural area. Whereas, for urban area these values were found to be 9 meters and 36.35 km/h. In general, if the drivers are moving at higher speeds they tend to anticipate the situation and respond to the lead vehicles at relatively higher distances to ensure safety.

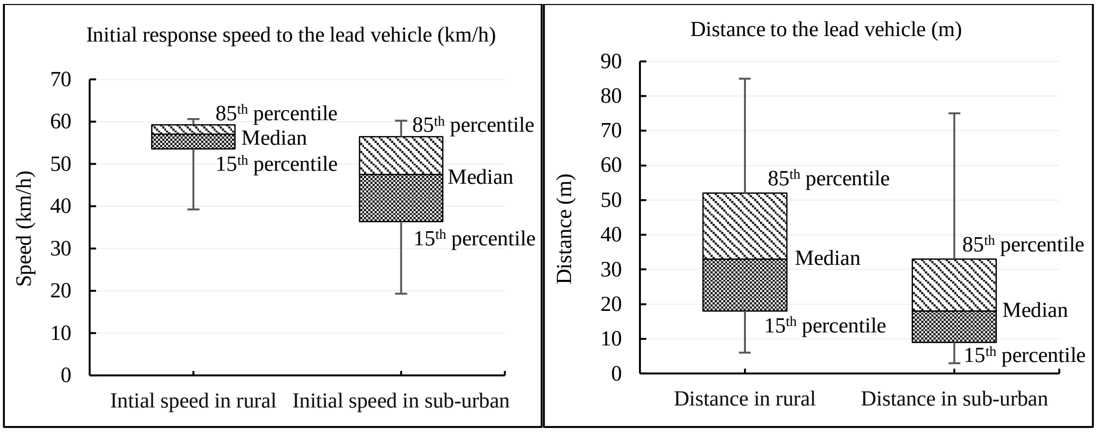

Fig. 7. Drivers' responses to lead vehicles in rural and suburban regions.

5. Summary and conclusions

In this study, we have analyzed the driver's behavior over rural and sub-urban regions for heterogeneous traffic conditions. The interactions with the other vehicles over various geometrical features are observed continuously in different time periods and the corresponding speed choices are presented. The naturalistic driving data is collected using five drivers, for 92 trips resulting in 69 travel hours. The subject drivers were informed about the objectives of the study and assured of no action against their employment. Driving performance data and the respective traffic situations are extracted for intersections and mid-block openings. It is observed that drivers are not responding to the geometric features in the absence of intersecting traffic. But, the speed choices are varying in the presence of crossing or turning vehicles at intersections and mid-block openings. The observed speed reductions near intersections and mid-block openings are 12.99 km/h and 15.28 km/h with the presence of crossing vehicles. The driver's responses to the lead vehicles are presented in terms of initial responding speed and the distance to the lead vehicle. Speed and distance choices are observed to be higher in the case of the rural area compared to the suburban region. The 15th percentile initial response speed values are 53.55 and 36.35 km/h in rural and sub-urban regions respectively, which means 85 percent of the time the drivers are responding at speeds higher than specified. The respective choice of distances to the lead vehicles is 18 m and 9 m in rural and suburban regions. Drivers' speed and distance choices as a response to lead vehicles are higher in rural area compared to suburban.

As per authors knowledge, no other study accounted for variations in driver's behavior under heterogeneous traffic conditions based on naturalistic driving data. As the observed traffic conditions exhibit violations in lane discipline, this study holds paramount importance in understanding driver's behavior in the complex traffic environment. The analysis results presented in this study are part of the ongoing research and involves extensive and exhaustive data collection and data extraction process. The variation in drivers' behavior based on the type of lead vehicle in different traffic environment is the future scope of this work. In future, the study extends to the development of risk scores to categorize the drivers into different categories such as conservative, normal and aggressive.

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