CHARACTERIZING DRIVING BEHAVIOUR UNDER MIXED TRAFFIC CONDITIONS USING INSTRUMENTED VEHICLES

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ABSTRACT

Road traffic is a dynamic system with interdependence among road users, vehicles, and infrastructure. Among these, the road user characteristics are the most complex, with great implications on safety. In 2019, with over 150,000 road fatalities in India, road safety stood as one of the top priorities in the road sector. Over 80% of accidents are reported to be due to faults of drivers. In this context, a comprehensive evaluation of driving behaviour under various road types and traffic conditions is necessary to promote road safety. Different drivers display distinct behaviours with unique driving characteristics. With limited existing studies on mixed traffic conditions as prevailing in India, a comprehensive study is being undertaken using instrumented vehicles, to better understand driving behaviour. Extensive field runs with 410 different drivers covering a total of 3840 km (175 hours of run time) were conducted in the city of Chennai. Inertial Measurement Unit (IMU) and Global Positioning System (GPS) were used in the vehicles to collect the data on acceleration/deceleration, speeds, and vehicular positions at high time resolution on various types of roads during different times of the day. Driving behaviour characteristics, like acceleration/deceleration, speed, travel time, and jerk variation across various driver groups, road types and sections, and time periods were analyzed. This paper presents the data collection methodology, data analysis, and key findings on driving characteristics from the above study. The data analysis revealed interesting insights on the influence of type of road, section (mid-block/intersection), time periods of travel, and driver age groups on acceleration/deceleration, travel time, and jerk. This study can be valuable in understanding driving behaviour in mixed traffic conditions and subsequently in devising measures to promote road safety.

Key words: Mixed Traffic, Instrumented Vehicles, Driving Characteristics.

1. INTRODUCTION

India has the second largest road network in the world, comprising about 5.5 million kilometers. Roadways carry around 85% and 60% of passenger and freight traffic, respectively. The growth in the road network, both in extent and quality, along with increasing personal incomes of people, has brought in rapid motorization. The growth of population and motor vehicle ownership, coupled with urbanization and inadequate public transport systems, has resulted in traffic congestion and road safety. One of the primary reasons for death or disability is road accidents. India has the dubious distinction of being among the countries with the poorest road safety record.

In the backdrop of the above introduction, the country's high priority issue is to promote road safety. Road safety has several dimensions - the road, road users, traffic, and the environment. Over 80% of accidents reported due to drivers' faults glaringly stands as the principal factor for accidents. Thus it is amply convincing that if the drivers' fault can be addressed in some way, safety will be promoted. Also, a variety of vehicle types moving with weak lane discipline further exacerbate the problem. The common driving actions seen are aggressive driving, risky overtaking, maneuvering through gaps in between the vehicles. Therefore, to understand drivers' fault reasons and accordingly tackle the safety issue, a thorough evaluation of driving behaviour under various road types, traffic, and environmental conditions is necessary.

This paper presents the analysis of driving behaviour characteristics, like acceleration/deceleration, speed, travel time, and jerk variation across various driver groups, road types and sections, and time periods. The paper's scope is limited to non-invasive and portable instrumentation of cars and field runs conducted through a sample of drivers. These runs were conducted in Chennai urban area under varying (low, medium, and congested) traffic conditions.

2. LITERATURE REVIEW

Driving behaviour plays a crucial role in traffic safety. Improper driving behaviour will lead to an increase in the probability of accident occurrence. To understand the driving behaviour, we need to assess driver actions and reactions. This section provides a brief overview of previous studies on driving behaviour data collection methods and driving behaviour characteristics.

2.1. Driving behaviour data collection methods

The driving behaviour data collection methods include self-reported instruments (Driving Behaviour Inventory (DBI), Driving Style Questionnaire (DSQ), Driving Behaviour Questionnaire (DBQ) (Sagberg et al., (2015)), observation by in-vehicle observer (Amado et al., (2014)), simulator study (Wakita et al., 2005), controlled field study with instrumented vehicle (Takeda et al., 2011), and naturalistic driving observation (Toledo & Lotan, 2006). Each method has its advantages and disadvantages. In the naturalistic studies, sensors are installed in the vehicles, and the driving behaviour data is collected with field runs. This approach gives a rich data set of multiple drivers with driving behaviour data over a period of time, which is the main advantage over the other methods.

The trajectory data collection also comes into the naturalistic driving studies category (Kanagaraj et al., (2015)). Here, a camera (sensor) is placed on a vantage point to collect different vehicles' driving behaviour data over a road section with limited length and road type. Mahapatra and Kumar (2018) instrumented the vehicle with Video-VBOX and collected the driving behaviour data from India's six cities.

2.2. Driving behaviour characteristics

Several authors have studied the driving behaviour characteristics. Mehar et al. (2013) found that cars' average speed on a six-lane highway is significantly higher than on a four-lane highway. Also, they found that the average acceleration of a car on a six-lane road is significantly different from the four-lane highway. Xu et al. (2015) conducted an experimental study on the lateral acceleration of cars in different environments in Sichuan, China. They gave different percentile values of lateral acceleration on six-lane, four-lane, and two-lane road types. Kanagaraj et al. (2015) analyzed the speed, acceleration, and deceleration characteristics of different vehicle types in longitudinal and lateral directions. The analysis corresponds to a 245 m road section with three lanes on one side. Pan et al. (2017) developed a risk driving evaluation model with the OBD (On-Board Diagnostic) data and explored the relevant factors of dangerous driving behaviour. They observed mileage, number of emergency brakes, maximum speed, and driving time as relevant factors. Omar et al. (2018) analyzed the acceleration and deceleration characteristics of a passenger car in Federal route FT050, Malaysia. They observed that vehicles have higher acceleration/deceleration time and distance and lower acceleration/deceleration rates at maximum speeds. Mahapatra and Maurya (2018) analyzed the driving characteristics of different vehicle types on 4-lane and 6-lane roads in lateral and longitudinal directions.

Jerk is defined as the rate of change acceleration or deceleration of a vehicle. In physical terms, jerk represents the level of discomfort caused by the vehicle. At first, the jerk was used as a performance measure in evaluating the shift quality and ride comfort (Huang & Wang, 2004). Later, authors suggested the use of jerk as a measure of risky driving style, probability of accident involvement, to detect safety-critical events (Bagdadi & Várhelyi, 2011, 2013; Ryder et al., 2019), to classify driving style (Murphey, Milton, & Kiliaris, 2009), and to identify aggressive drivers (Feng et al., 2017).

The trajectory data collection by video camera covers only specific road types and a short section of length. In this regard, a naturalistic driving study with in-vehicle sensors covering driving behaviour across various road types, sections, and different times of the day, is a beneficial choice. The literature on driving behaviour presents mostly those studies conducted in countries where traffic flow is more homogeneous and orderly. However, on Indian roads, traffic is heterogeneous, disorderly, and characterized by unpredictable and rash driving styles. However, studies on Indian traffic do not consider the variation of driving behaviour on two-lane roads. Also, the literature did not reveal jerk variation in Indian traffic conditions. To address the literature gaps, we investigate the naturalistic driving behaviour by analyzing vehicle speed, acceleration, deceleration, and jerk characteristics under various road and traffic conditions on city roads.

The remainder of this paper is organized in the following sections. The next section describes the data collection process. In section 4, the methodology for data analysis is discussed. The analysis of the data is presented in section 5. The final section presents the summary and key findings drawn from the study.

3. DATA COLLECTION

Inertial Measurement Unit (IMU) developed by Centre for Development of Advanced Computing - Trivandrum (CDAC-T) and GPS modules were used to collect data through field runs in Chennai. Figure 1 (a) shows the IMU unit and the GPS. The module was placed on the dashboard of the car during the field run as shown in Figure 1 (b). The data collection was conducted on 12 routes with an average trip length of 9.5 km in Chennai. The route map is shown in Figure 2. These routes cover different road types. Moreover, to capture variations in driving behaviour and traffic conditions, the field runs were conducted at different times of the day (6:00 A.M to 11:00 P.M with an interval of 30 min) with different drivers for each trip. A total of 410 field runs with 410 different drivers covering 3840 km, and 175 hours of driving data have been collected. The details of different road types covered in the field runs are shown in Table 1. The predominant road types include 39% of two-way divided four-lane (2W-D-4L), 27% of two-way divided six-lane (2W-D-6L), and 23% of two-way undivided two-lane roads (2W-UD-2L). Other road types constitute 11% of field runs. Out of 410 drivers, 29% of drivers belong to the 18-30 years age group, 59% to 31-45 years, and 12% to greater than 45 years.

(a) IMU-GPS Module **(b) IMU-GPS module on the dashboard of a car**

Figure 1: Instrumentation in test car

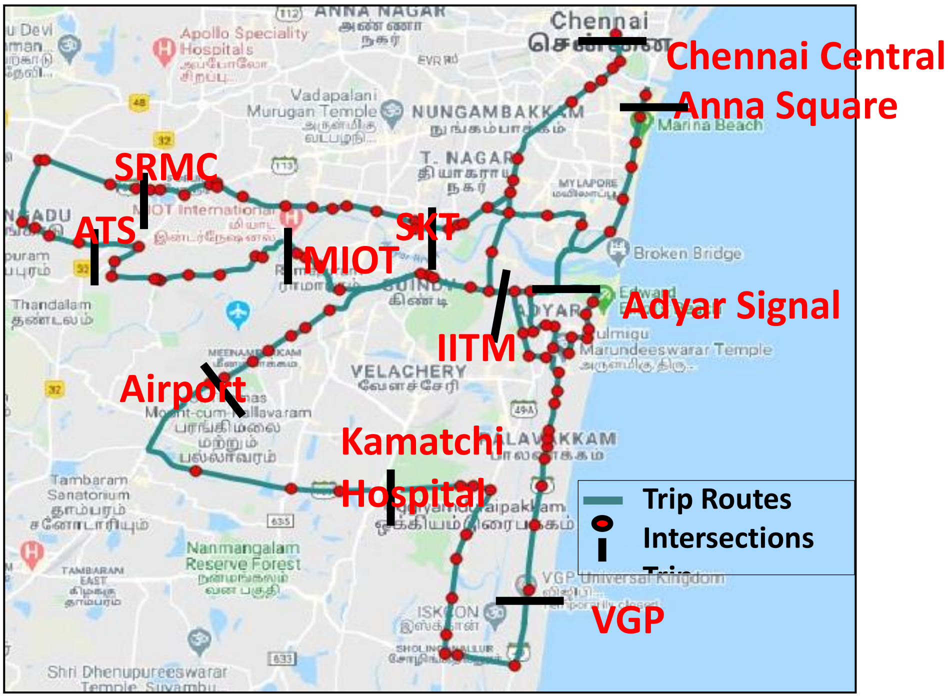


Figure 2: Routes for Data Collection in Chennai

Table 1: Different Road Types Covered in Field Runs

Road Type	Length (km)	% Coverage
2W-D-4L	1496	39
2W-D-6L	1048	27
2W-UD-2L	865	23
Others	431	11

2W – Two-Way; D – Divided; UD – Undivided; 4L – Four-lane; 6L – Six-lane; 2L – Two-lane

The Inertial Measurement Unit (IMU) consists of three sensors – an accelerometer, gyroscope, and magnetometer. In this study, only accelerometer values are considered. Acceleration/deceleration (m/s^2) data is obtained from accelerometer. Global Positioning System (GPS) gives the vehicular position in latitude and longitude, and speed (km/h) data. IMU and GPS units were synced and give the data at 0.1 s time resolution.

4. METHODOLOGY

The methodology involves the instrumentation of the vehicle (car) with sensors such as IMU (accelerometer, gyroscope, magnetometer), and GPS. These sensors are intended to capture the dynamics of the vehicle. The field runs under three broad scenarios of the low, medium, and dense traffic will lead to driving behaviour insights. The overall methodology of this paper is shown in Figure 3.

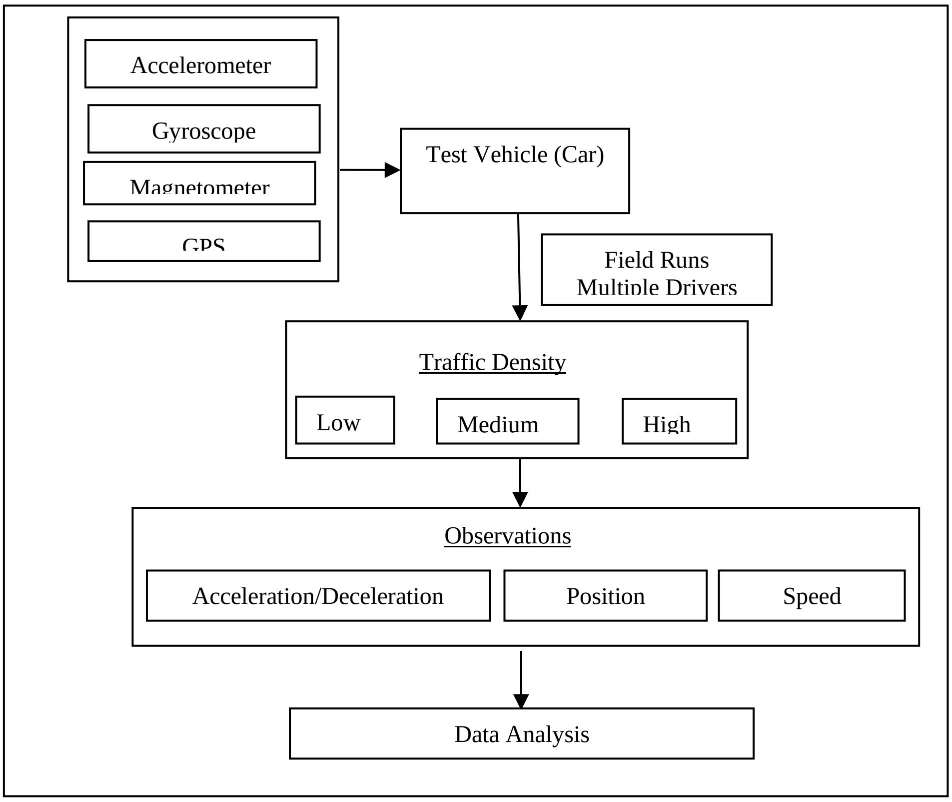


Figure 3: Methodology

5. DATA ANALYSIS

Each trip (field run) is divided into mid-blocks and intersections. 100 m on either side of the stop-line at an intersection plus the intersection width is categorized as an intersection portion. For each route, the drivers' driving behaviour on mid-blocks and intersections is analyzed based on road types, driver age groups, and time of the trip (surrogate to traffic conditions).

5.1. Speed Characteristics

Speed is an important measure indicative of road type. In this regard, to investigate the speed profiles on different road types, speeds are recorded by conducting field runs with GPS. The speed variation across road types is shown in Figure 4. It is observed that with an increase in the number of lanes, speeds are also increasing. This is believed to be due to larger carriageway width facilitating higher average speeds. In addition, these roads are also generally divided and devoid of side friction, further aiding in increased speeds.

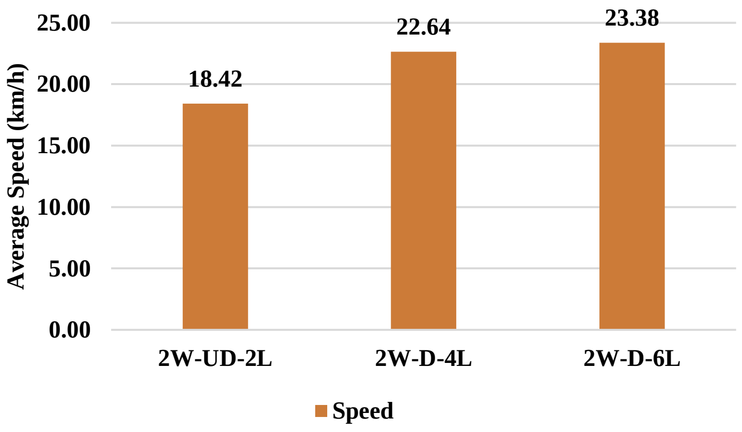


Figure 4: Speed variation across road types

5.2. Acceleration/Deceleration Characteristics

Detailed analysis of acceleration/deceleration characteristics across different road types is carried out. The accelerometer provides x, y, and z-axis data, where the x-axis represents the longitudinal direction (along the path of travel), the y-axis is the lateral direction, and the z-axis is the vertical direction. The positive longitudinal accelerometer values indicate acceleration, whereas negative values regard vehicular deceleration. The positive lateral accelerometer values indicate left side movement, whereas negative values correspond to the right-side movement. Figure 5 presents the average acceleration/deceleration behaviour across longitudinal and lateral directions with respect to different road types. Results show that longitudinal values are higher than lateral values for all the road types. Two-way undivided two-lane (2W-UD-2L) roads are seen to have maximum acceleration/deceleration values. This is believed to be due to lower traffic volumes interrupted by vehicles coming in the opposite direction, leading to successive decelerations and accelerations. In addition, these roads are generally characterized by side friction, which causes deviations from the designated lane, leading to higher lateral acceleration. Mahapatra and Maurya (2018) analyzed the dynamic vehicular parameters under heterogeneous traffic stream with non-lane discipline. The naturalistic data collection technique adopted in this study is similar to our data collection approach. The average values of longitudinal acceleration, longitudinal deceleration, and lateral acceleration of 4-lane/6-lane roads obtained in their study are 0.53 m/s^2, -0.56 m/s^2, and 0.35 m/s^2, respectively. These values are at par with our study.

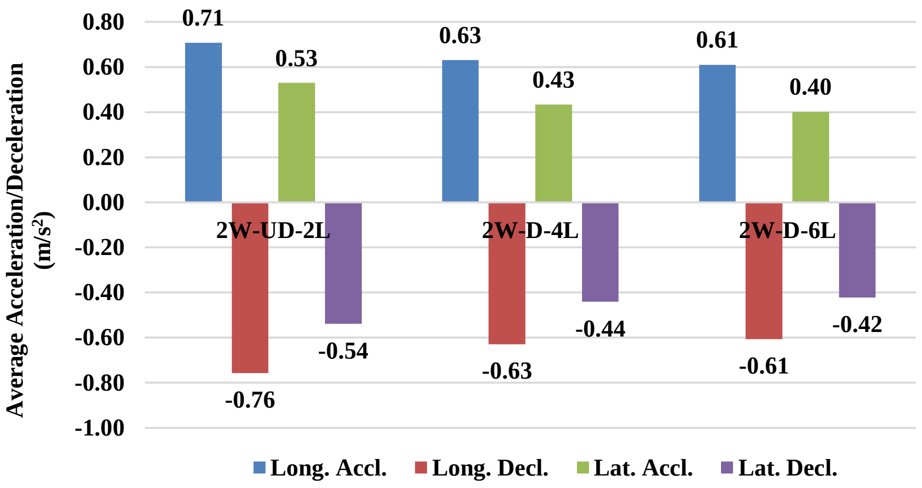


Figure 5: Acceleration/deceleration variation across longitudinal and lateral directions for various road types

5.3. Travel time Characteristics

Travel times on roads primarily depend on traffic volumes, which again vary during peak and off-peak periods. To determine the peak periods, delay as a function of travel time (tt) and free-flow travel time (Equation 1) is used. Free-flow travel time is taken as the minimum trip time in that route. The length of each route varies, and to normalize across the routes, we considered delay per 100 m in this study. Figure 6 presents the delay variation across the routes. It is observed that 7:30 A.M to 10:30 A.M and 4:30 P.M to 8:00 P.M are the morning and evening peak hours, respectively.

$$d_t^r = tt_t^r - fft^r \qquad (1)$$

where,

$d^r{}_t$ = Delay of trip t in route r
$tt^r{}_t$ = Travel time of trip t in route r
fft^r = Freeflow travel time in route r

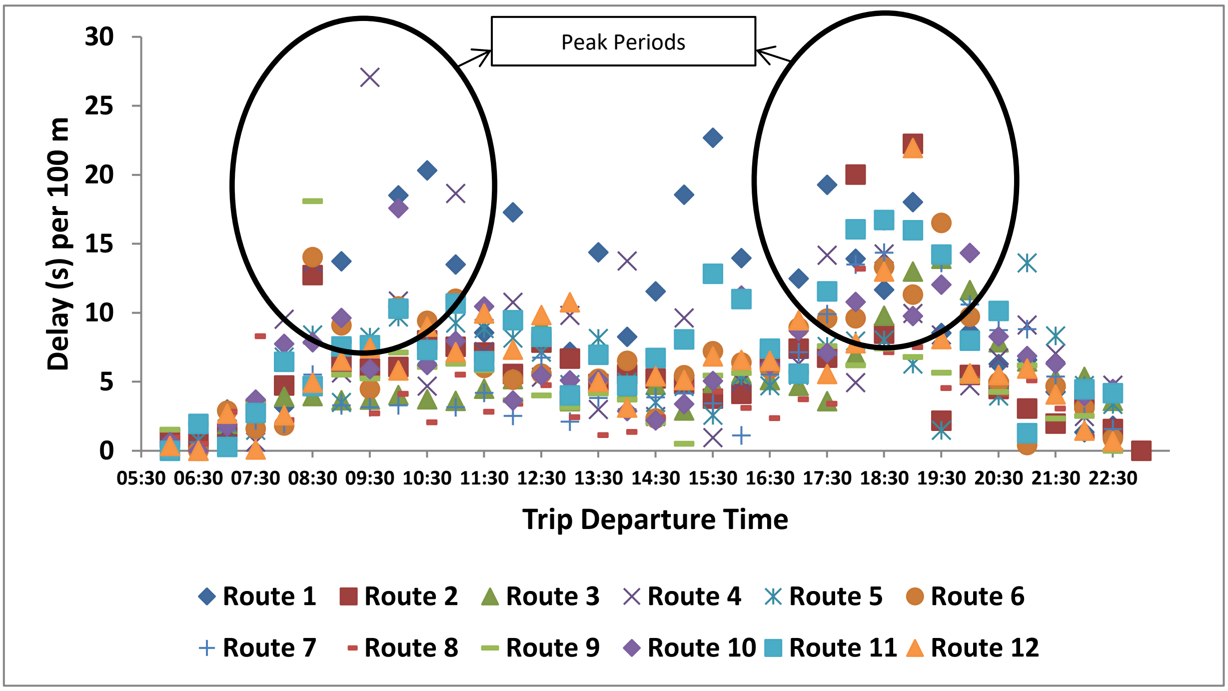
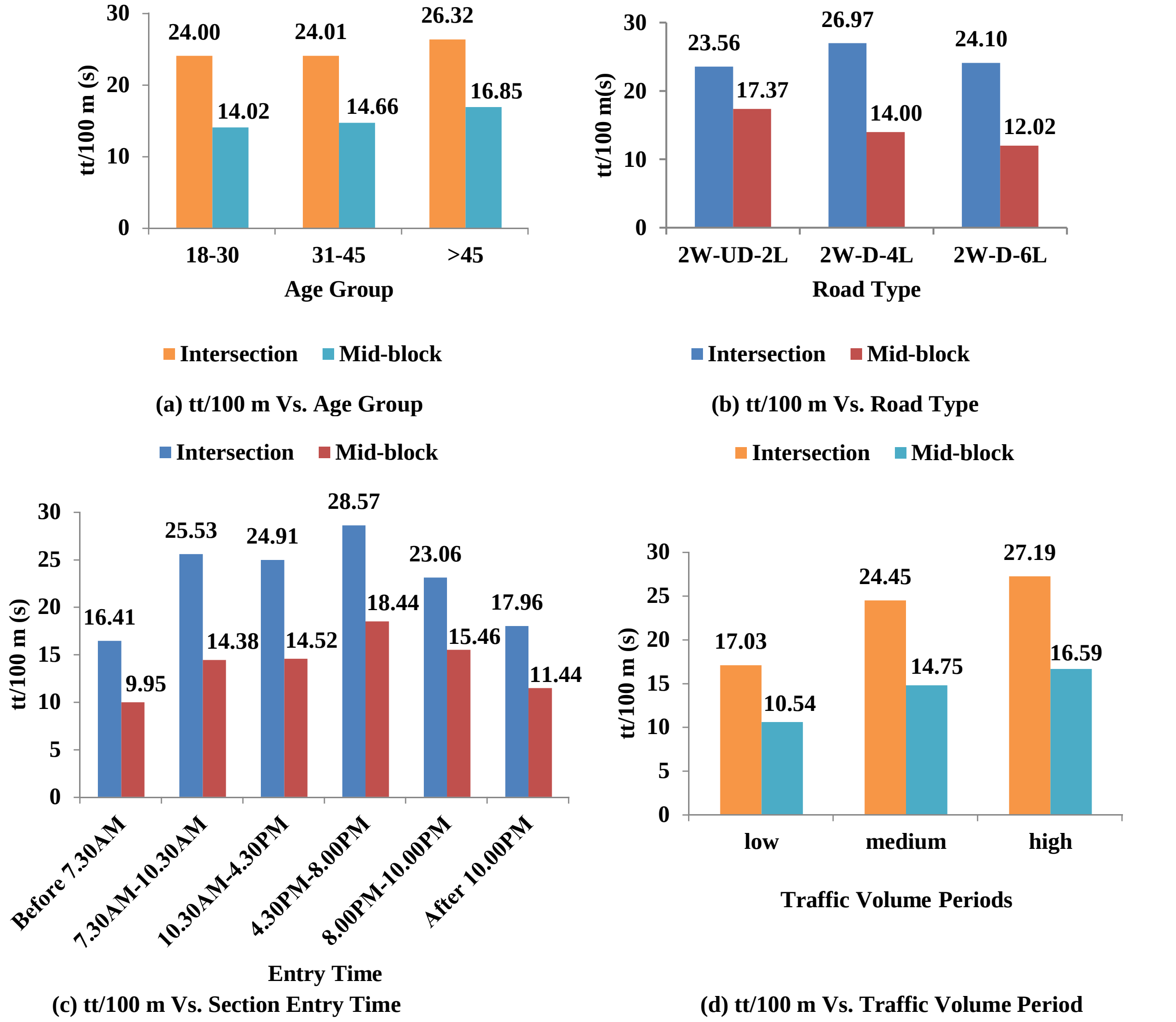


Figure 6: Delay per 100 m variation across routes

Figure 7 presents the variation of travel time per 100 m across mid-blocks and intersections with respect to driver age groups, road types, and traffic conditions. Intersections show high travel times compared to mid-block sections in all the categories. Figure 7 (a) shows that with an increase in the driver age group, there is an increase in travel time, which indicates that older drivers are more cautious. Figure 7 (b) shows that 2W-UD-2L intersections have lesser travel times due to less traffic and uncontrolled intersections. On the other hand, 2W-D-4L intersections have higher travel times because of higher traffic and resulting congestion. Time of the day is used as a surrogate to categorize volumes into low, medium, and high. The time of the day is categorized into six groups, as shown in Figure 7 (c). Entry time periods before 7:30 A.M and after 10:00 P.M are grouped into low volume periods. Morning peak hours (7:30 A.M - 10:30 A.M) and evening peak hours (4:30 P.M - 8:00 P.M) are grouped into high volume periods. Off-peak hours (10:30 A.M - 4:30 P.M and 8:00 P.M - 10:00 P.M) are grouped into medium volume periods. Figure 7 (d) shows that the higher volume traffic periods result in higher travel times as compared to those of lower volume periods, as expected.



(a) tt/100 m Vs. Age Group

(b) tt/100 m Vs. Road Type

(c) tt/100 m Vs. Section Entry Time

(d) tt/100 m Vs. Traffic Volume Period

Figure 7: Travel time variation across mid-blocks and intersections with respect to driver age groups, road types, and traffic conditions

5.4. Longitudinal Jerk Characteristics

From the literature, it is observed that jerk can also be an indicator of driving behaviour. To understand the jerk variation in mixed traffic conditions, it is analyzed across different road types. Jerk is a derived parameter from acceleration and is defined as the rate of change of acceleration with time (m/s^3). Jerk can be either positive or negative. Peak to peak jerk is the difference between the positive peak jerk to the next consecutive negative peak jerk value and vice versa. Figure 8 presents jerk values across different road types. 2W-UD-2L roads show maximum jerk values because of its two-way traffic movements and side friction. Feng et al. (2017) analyzed the longitudinal jerk characteristics using sensor data from a USA's naturalistic study. The authors obtained the 99.9th percentile values for positive and negative jerks as 1.07 m/s^3 and -1.47 m/s^3, respectively. In our paper, the 99.9th percentile values are 5.73 m/s^3 for the positive jerk and -5.57 m/s^3 for the negative jerk. These values are much higher. This is believed to be due to jerky driving styles under heterogeneous and lane-less traffic conditions. It is also a characteristic of drivers in India's urban areas, where drivers are generally aggressive and tend to weave through traffic to get ahead. These also contribute to higher jerk values.

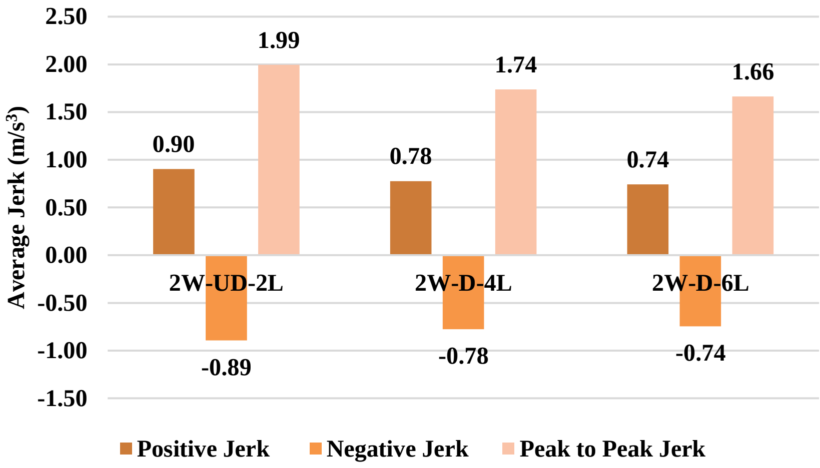


Figure 8: Jerk variation across road types

6. CONCLUSIONS

Driving behaviour was captured in the present study using instrumented vehicles fitted with IMU and GPS sensors and through field runs in real traffic conditions. Driving characteristics like acceleration/deceleration, speed, travel time, and jerk variation across various driver groups, road types and sections, and time periods were analyzed. Based on the study, the following conclusions are drawn.

- Two-way undivided two-lane roads show higher acceleration/deceleration values in longitudinal and lateral directions than other road types. This is believed to be due to lower traffic volumes interrupted by vehicles coming in the opposite direction, leading to successive decelerations and accelerations.
- Intersections have interrupted traffic flow conditions and hence have higher travel times compared to mid-block sections.
- Elderly drivers are more cautious and hence take a longer time to cover the same distance.
- Peak periods represent high traffic volume conditions and hence show higher travel times compared to off-peak periods.
- Two-way undivided two-lane roads show higher jerk values as compared to those of other road types. These roads are generally characterized by side friction, which necessitates deviations from the designated lane, leading to higher jerk values.

The limitation of this study is that it has not evaluated driver risk propensity under mixed traffic conditions. This task is currently underway. However, the contribution of this paper is a better understanding of driving behaviour and related parameters through exhaustive field runs of instrumented vehicles under various scenarios of road types and time periods for a large sample of drivers.

This study can serve as an initial step towards assessing driving behaviour, which may ultimately find use in developing technology solutions in the form of dashboard signs, messages, warnings, etc., to alert and assist the drivers. This will be valuable to automobile manufacturing industries. Further work includes the derivation of risk propensity indicators from the primary driving characteristics (acceleration/deceleration, speed), analysis of driving behaviour at intersections, and determining the influence of side friction characteristics on two-way undivided two-lane roads.

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