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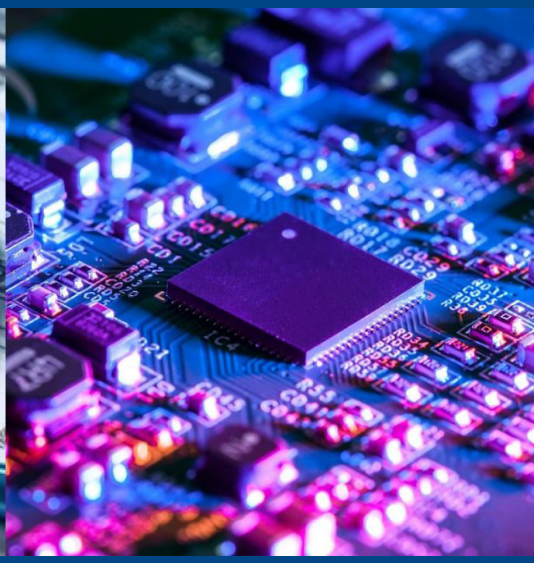

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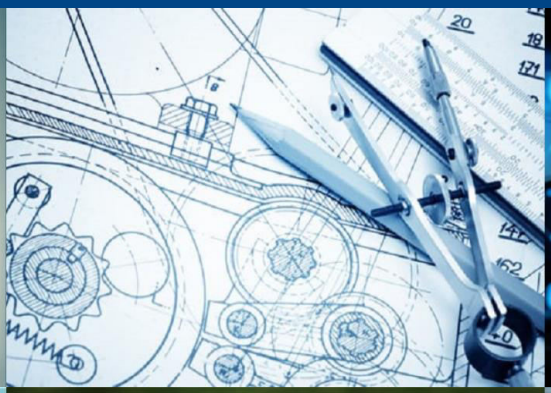

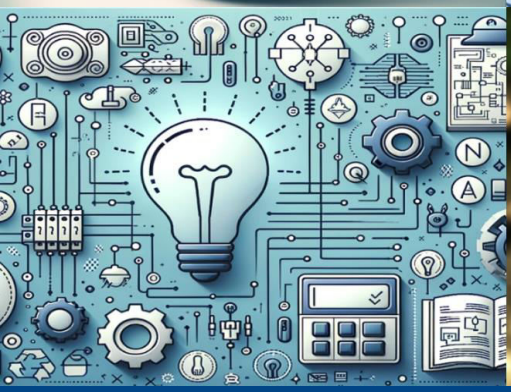

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An Analytical Study of Vehicle–Pedestrian Interaction and Its Influence on Traffic Flow Dynamics

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ABSTRACT: Vehicle–pedestrian interaction is one of most significant aspects of urban transportation systems especially in densely populated cities where pedestrians & vehicles frequently share road space. Interaction between moving vehicles & crossing pedestrians directly affects traffic flow characteristics, roadway capacity, travel speed, delay and overall road safety. Rapid urbanization, population growth & increasing vehicular ownership have intensified complexity of traffic operations in urban areas. In many developing countries, mixed traffic conditions, lack of proper pedestrian infrastructure, and non-compliance with traffic regulations create severe disturbances in traffic flow. This examines relationship between pedestrian movement & vehicular traffic dynamics, emphasizing pedestrian crossing activities influence vehicle speed, density, traffic volume & roadway performance. These also highlights importance of pedestrian safety measures & efficient traffic management strategies to minimize conflicts between vehicles and pedestrians.

KEYWORDS: Pedestrian Behavior, Road Safety, Vehicle–Pedestrian Interaction, Traffic Flow Dynamics and Traffic Congestion

I. INTRODUCTION

Transportation systems play a crucial role in economic growth, urban development & social connectivity. Roads are most commonly used transportation facilities where vehicles & pedestrians interact continuously. Pedestrians constitute an essential component of urban traffic systems because walking is most basic & universal mode of transportation. Coexistence of pedestrians and vehicles on urban roads often leads to operational conflicts especially at intersections, crosswalks, bus stops & commercial zones.

Vehicle–pedestrian interaction refers to mutual influence between vehicular movement & pedestrian activities on roadways. When pedestrians cross roads, vehicles are often forced to slow down, stop or change lanes thereby affecting traffic flow dynamics. Heavy vehicular traffic creates difficulties for pedestrians attempting to cross roads safely. These interactions become more complicated under mixed traffic conditions where different vehicle categories operate simultaneously without strict lane discipline.

In urban areas, increasing traffic congestion & pedestrian accidents have become major concerns for traffic engineers and urban planners. Understanding impact of pedestrian crossings on traffic flow characteristics is therefore essential for improving roadway efficiency & enhancing pedestrian safety. This studies on vehicle–pedestrian interaction help in developing suitable traffic control measures, pedestrian facilities and urban transportation policies.

II. OBJECTIVES OF STUDY

1. To analyze characteristics of vehicle–pedestrian interaction under urban traffic conditions.
2. To evaluate influence of pedestrian crossings on traffic flow parameters.
3. To quantify vehicular delay & capacity reduction due to pedestrian movements.
4. To develop analytical relationships describing traffic flow dynamics under pedestrian interference.
5. To suggest measures for improving pedestrian safety while maintaining traffic efficiency.

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III. LITERATURE REVIEWS

Chandra, S. & Dey, P. P. (2025) Authors proposed analytical frameworks to study vehicle–pedestrian interaction under mixed traffic conditions. Their study highlighted that pedestrian activities significantly influence operational performance of roadways, particularly at uncontrolled crossings, intersections & densely populated commercial corridors. These explained that frequent pedestrian movements interrupt continuity of vehicular traffic leading to reductions in average travel speed, increased delay & fluctuations in traffic density.

Saha, P. & Chandra, S. (2024) This study investigates influence of pedestrian crossing behavior on vehicular speed variability under mixed traffic conditions. Field data were collected at urban midblock locations with significant pedestrian activity using videographic techniques. Pedestrian parameters as crossing frequency, gap acceptance & waiting time were analyzed alongside vehicular speed profiles. Study focused on urban midblock locations where pedestrian activity is relatively high and frequently interacts with moving traffic, making these sites suitable for behavioral analysis.

Banerjee, A. & Maitra, B. (2023) Authors examined concept of Pedestrian Level of Service at urban road crossings & highlighted close relationship between pedestrian comfort, safety & vehicular traffic performance. Their study emphasized that pedestrian facilities should not only focus on movement convenience but also consider impact of pedestrian activity on overall traffic operations. They analyzed conditions to evaluate crossing efficiency.

Huang, H. & Abdel M. (2022) Study emphasized operational significance of pedestrian activity in influencing traffic performance & safety outcomes. These demonstrated that increased pedestrian movements significantly influence traffic performance by affecting vehicle speed, flow & congestion levels while also raising likelihood of accidents. Their findings highlight operational & safety significance of pedestrian behavior & emphasize necessity of incorporating pedestrian dynamics into urban traffic management & planning strategies.

Kamble, A. & Chandra, S. (2021) They identified pedestrian volume as primary factor affecting delay & queue length under urban mixed traffic conditions. Pedestrian volume is primary factor influencing vehicular delay & queue formation. Higher pedestrian flows lead to significant disruptions in vehicle movement causing speed reductions & increased congestion.

Zhou, H. & Hu, S. (2018) They proposed modified speed–flow curves suitable for heterogeneous traffic conditions. Frequent pedestrian crossings & interruptions cause deviations from conventional speed–flow patterns leading to reduced speeds & unstable traffic conditions. Authors proposed modified speed–flow curves tailored for heterogeneous traffic conditions, incorporating both vehicular & pedestrian dynamics.

Rahman, M. & Okura, I. (2017) Capacity reduction due to pedestrian movements & concluded that increasing pedestrian volume leads to non-linear reductions in roadway capacity especially on urban arterials. Study found that increasing pedestrian volume causes non-linear reductions in capacity due to frequent interruptions in vehicular flow.

Das, S. & Al-Rukaibi, F. (2016) Study examined pedestrian impacts on urban traffic operations & emphasized need for pedestrian-inclusive models. Pedestrian movements especially at midblock sections & intersections significantly influence vehicular flow leading to speed reduction, increased delays & decreased roadway capacity.

Zhang, J. & Seyfried, A. (2015) They examined pedestrian–vehicle conflicts at signalized intersections & highlighted that pedestrian crossing phases significantly reduce effective green time for vehicles thereby affecting saturation flow & intersection capacity under dense urban traffic conditions. Pedestrian crossing phases significantly reduce effective green time available for vehicles, directly influencing saturation flow rates & intersection capacity.

IV. METHODOLOGY

Concept of Pedestrian Behavior in Traffic Streams

Pedestrian behavior in traffic streams describes people interact with moving vehicles while walking or crossing roads. It plays an important role in urban transportation studies, particularly under mixed traffic conditions. Pedestrians make

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crossing decisions by judging vehicle speed, traffic flow road width and available crossing opportunities. A key factor is gap acceptance where pedestrians select a suitable time gap between vehicles for safe crossing. Age, walking speed and urgency also influence their movement patterns. Unsafe crossing practices and frequent vehicle–pedestrian interactions can reduce traffic efficiency and increase accident risk. Therefore, studying pedestrian behavior helps in improving road safety and traffic management systems.

Description of Study Area

Present study is conducted in Sikar an important urban center in state of Rajasthan. Sikar lies in northeastern part of Rajasthan & serves as a major administrative, commercial & educational hub of Shekhawati region. Because of its rapid urban growth, city has experienced a considerable increase in both vehicular movement & pedestrian activity. Sikar has a mixed traffic environment consisting of two-wheelers, cars, auto-rickshaws, buses, bicycles, handcarts & pedestrians sharing same road space. Presence of markets, schools, colleges, hospitals, bus terminals & commercial establishments generate heavy pedestrian movement throughout day. This creates frequent interaction between pedestrians & vehicles particularly at intersections, mid-block crossing locations & busy market areas. Roads in many parts of city are characterized by moderate to high traffic volume, irregular parking, roadside commercial activities & limited pedestrian facilities.

Major Study Locations

1. Clock Tower Market Area (Ghanta Ghar)

The Clock Tower (Ghanta Ghar) area is one of busiest commercial zones in Sikar. Location experiences continuous pedestrian activity due to presence of retail shops, street vendors, markets & commercial establishments. Narrow road widths, roadside parking & frequent stopping of vehicles contribute to congestion & reduced traffic speed. Pedestrians often cross roadway at multiple undesignated points, creating frequent interaction with moving vehicles.

Figure 1: Clock Tower Market Area (Ghanta Ghar)

2. Sikar Bus Stand Area

Bus stand area represents a major transportation node within city. The location experiences high traffic volume throughout day due to movement of buses, auto-rickshaws, private vehicles & pedestrians. Passenger boarding & alighting activities generate significant pedestrian flow near roadway. Informal pedestrian crossings and temporary vehicle stoppages frequently disturb normal traffic movement & contribute to traffic conflicts.

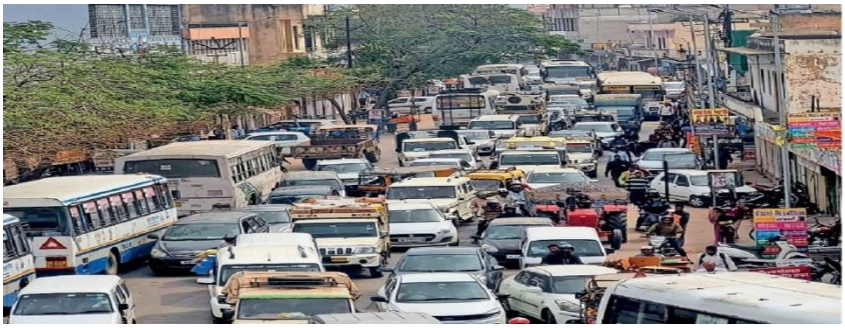

Figure 2: Sikar Bus Stand Area

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3. Piprali Road

Piprali Road is one of major arterial roads in Sikar & serves as an important entry & exit corridor for the city. The road carries substantial traffic volume including buses, trucks, two-wheelers & private vehicles. Educational institutions, commercial centers & residential developments located along corridor generate considerable pedestrian activity. Pedestrians frequently cross road at random locations due to limited crossing infrastructure.

Figure 3: Piprali Road

Data Collection Methods

To analyze vehicle–pedestrian interaction & its influence on traffic flow dynamics in Sikar, two primary field surveys are generally conducted: Traffic Volume Survey & Pedestrian Movement Survey. These surveys help quantify characteristics of both vehicular & pedestrian streams at selected intersections and mid-block locations.

1. Traffic Volume Survey

Traffic volume survey is conducted to measure number & type of vehicles passing through selected study locations during specific time intervals. It provides basic data required for evaluating traffic intensity, roadway utilization and extent to which vehicle movement is affected by pedestrian activity. Survey is usually carried out through direct field observation during peak & off-peak hours. A manual classified count method may be adopted in which all vehicles are categorized into classes as two-wheelers, cars, auto-rickshaws, buses, trucks, bicycles & non-motorized vehicles. Vehicles moving in each direction are counted separately. At each study point, observations are generally recorded at short intervals as 5-minute or 15-minute periods and later converted into hourly traffic volume. This helps identify traffic fluctuations during observation period. This information is important for analyzing pedestrian crossings interrupt traffic flow, reduce speed & create delays or queues.

2. Pedestrian movement survey

Pedestrian movement survey is conducted to understand pedestrian crossing behavior & its interaction with moving vehicles. This survey focuses on pedestrians use roadway, choose crossing points & respond to traffic conditions. Field observations are made at selected locations with high pedestrian activity as market roads, intersections, educational zones & bus stop areas in Sikar. Pedestrians crossing road are observed continuously during selected time periods. Pedestrian characteristics as age group, walking speed & tendency to cross individually or in groups may also be recorded wherever relevant during field observations in Sikar. These characteristics help explain differences in crossing behavior among various pedestrians. Children & elderly pedestrians generally move more slowly and therefore require larger gaps for safe crossing while young adults often accept comparatively smaller gaps. Group crossing is also common in market areas, near schools & near bus stops, where several pedestrians cross together instead of individually. Such behavior can influence both crossing time and the response of approaching drivers.

Data Collection

A videographic traffic survey was conducted at selected locations in Sikar district of Rajasthan under normal weather conditions on regular working days. Study locations included major urban & semi-urban of Sikar. Survey was undertaken during peak traffic periods namely from 8:00 AM to 10:00 AM in morning and from 4:00 PM to 6:00 PM in the evening. Video camera was installed on elevated locations as rooftops or nearby buildings to obtain a clear view

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of roadway sections. For measurement of vehicle speed & traffic flow, selected road stretches were divided into 20-meter segments using white cello tape markings. Recorded videos were subsequently analyzed in traffic monitoring & data analysis unit. Data regarding pedestrian & vehicular characteristics were extracted at 5-minute intervals. To evaluate effect of pedestrian crossings on vehicular movement, observed short-duration traffic data were converted into equivalent hourly traffic flow characteristics. Collected data included pedestrian volume, vehicle classification, vehicular flow rate & vehicle speed.

V. RESULT & DISCUSSION

1. Pedestrian Crossing Characteristics

Table 1: Pedestrian Crossing Characteristics

Parameter	Standard Value	Observed Value
Crossing width	3 – 12 m	7.5 m
Pedestrian walking speed	1.0 – 1.5 m/s	1.24 m/s
Average waiting time	5 – 30 s	14 s
Pedestrian volume	100 – 1200 pedestrians/hour	685 pedestrians/hour
Road occupancy time	2 – 12 s	6.1 s

Observed pedestrian crossing characteristics fall within standard range and indicate moderate pedestrian activity at the study location. Crossing width was observed as 7.5 m which lies within standard range of 3–12 m. This width provides sufficient space for pedestrian movement while still influencing vehicle operations during crossing activity. Pedestrian walking speed was recorded as 1.24 m/s which is within standard range of 1.0–1.5 m/s. This suggests normal pedestrian movement under urban traffic conditions. Average waiting time was found to be 14 s which also lies within standard range of 5–30 s. This indicates that pedestrians experienced moderate delay before finding acceptable gaps in traffic. Pedestrian volume was observed as 685 pedestrians/hour falling within standard range of 100–1200 pedestrians/hour. This reflects a relatively high level of pedestrian crossing demand during the observation period. Road occupancy time was recorded as 6.1 s which lies within the standard range of 2–12 s. This indicates average time during which the roadway remained occupied by crossing pedestrians. Overall observed values show that pedestrian crossing activity had a noticeable influence on traffic flow. Moderate waiting time, considerable pedestrian volume & road occupancy period indicate regular vehicle–pedestrian interaction.

2. Pedestrian Waiting Time Analysis

Pedestrian waiting time is an important parameter in vehicle–pedestrian interaction because it directly influences crossing behavior, gap acceptance & level of conflict between pedestrians & vehicles. It refers to time a pedestrian spends waiting at roadside before finding a suitable opportunity to cross road safely.

Table 2: Pedestrian Waiting Time Analysis

Parameter	Standard Value	Observed Value
Minimum waiting time	1 – 5 s	3 s
Average waiting time	5 – 30 s	14 s
Maximum waiting time	20 – 60 s	38 s

Observed pedestrian waiting time values fall within standard range & indicate moderate delay experienced by pedestrians before crossing. Minimum waiting time was observed as 3 s which lies within standard range of 1–5 s. This indicates that under favorable traffic gaps, some pedestrians were able to begin crossing with very little delay. Average waiting time was recorded as 14 s which falls within standard range of 5–30 s. This suggests that pedestrians generally

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had to wait a moderate amount of time before finding suitable gaps in traffic stream. Maximum waiting time was observed as 38 s, which also lies within the standard range of 20–60 s. This indicates that during periods of heavier traffic flow, some pedestrians experienced considerably longer delays.

Overall results show that pedestrian waiting time increased with traffic density & reduced availability of acceptable gaps. Observed average waiting time of 14 s indicates noticeable pedestrian delay while maximum waiting time of 38 s suggests that continuous traffic flow occasionally restricted immediate crossing opportunities. In urban traffic conditions as those observed in Jaipur, longer pedestrian waiting times often encourage smaller gap acceptance, which can increase vehicle–pedestrian interaction & localized traffic disturbance.

3. Vehicle Yielding Behavior

Table 3: Vehicle Yielding Behavior

Parameter	Standard Value	Observed Value
Yielding rate	20% – 70%	42%
Complete stop rate	10% – 40%	18%
Partial yielding rate	15% – 35%	24%
Non-yielding rate	30% – 80%	58%

Observed values of vehicle yielding behavior fall within standard range & reflect moderate driver compliance at pedestrian crossing locations. Yielding rate was observed as 42% which lies within standard range of 20%–70%. This indicates that less than half of the approaching vehicles yielded to pedestrians showing moderate driver responsiveness. Complete stop rate was recorded as 18% which falls within standard range of 10%–40%. This suggests that a limited number of drivers came to a full stop to allow pedestrians to cross safely. Partial yielding rate was observed as 24% which lies within the standard range of 15%–35%. This indicates that some drivers reduced speed without completely stopping allowing pedestrians to cross with caution. Non-yielding rate was found to be 58% which also falls within standard range of 30%–80%. This shows that more than half of approaching vehicles did not yield causing pedestrians to wait longer for suitable crossing opportunities. Overall results indicate that non-yielding behavior was more dominant than yielding behavior. Relatively high non-yielding rate of 58% contributed to increased pedestrian waiting time & influenced gap acceptance decisions.

4. Effect on Traffic Speed

Table 4: Effect of Pedestrian Activity on Traffic Speed Comparison

Traffic condition	Average free-flow speed (km/h)	Observed average speed (km/h)	Speed reduction (%)
Low traffic	42	38	9.5
Moderate traffic	38	31	26.2
Heavy traffic	32	24	42.9

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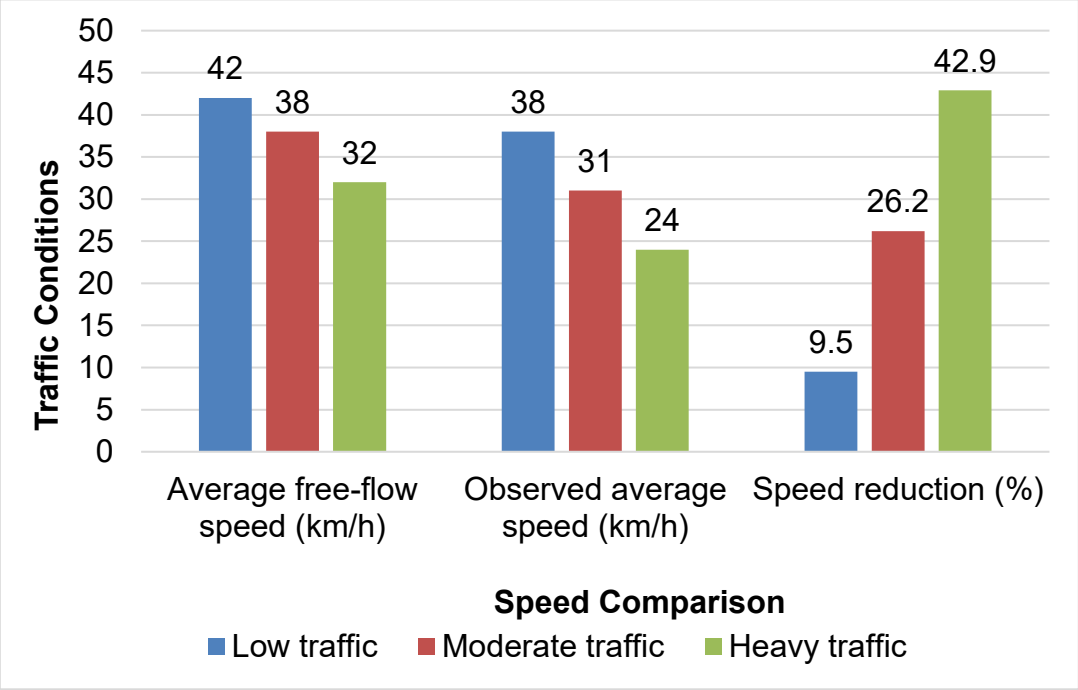

Figure 4: Effect of Pedestrian Activity on Traffic Speed Comparison

These illustrates effect of pedestrian activity on traffic speed under different traffic conditions. Comparison between free-flow speed & observed speed clearly indicates that pedestrian movement has a significant impact on reducing vehicle speed. Under low traffic conditions, average free-flow speed is 42 km/h while observed average speed is 38 km/h resulting in a 9.5% reduction. This shows that at low traffic volumes, pedestrian activity causes only minor speed variation & vehicles can maintain near-normal movement. Under moderate traffic conditions, observed average speed decreases to 31 km/h which corresponds to a 26.2% reduction in speed. This indicates that increased pedestrian crossings start to interfere more frequently with vehicle movement leading to noticeable speed reduction. Under heavy traffic conditions, observed average speed drops significantly to 24 km/h resulting in a 42.9% reduction. This clearly shows that high pedestrian activity combined with dense traffic causes severe disruption in traffic flow forcing vehicles to slow down considerably. Results demonstrate that increasing pedestrian activity leads to a continuous decline in traffic speed. This reduction in speed reflects reduced traffic efficiency, increased interaction between vehicles & pedestrians & greater instability in traffic flow under congested conditions.

VI. CONCLUSION

The present study was carried out in Sikar, a rapidly developing urban center of Rajasthan where increasing pedestrian activity and mixed traffic conditions create frequent interaction between vehicles and pedestrians. Due to the presence of markets, schools, hospitals, bus terminals and commercial establishments, pedestrian movement remains high throughout day, particularly at intersections & busy roadside areas. Study observed that pedestrian crossing characteristics remained within standard limits indicating moderate but continuous pedestrian activity.

Analysis revealed that pedestrian waiting time increased with traffic density and reduced availability of safe gaps. Average waiting time of 14 seconds and maximum waiting time of 38 seconds indicate noticeable delays faced by pedestrians during road crossing. Such delays often encourage pedestrians to accept smaller traffic gaps, increasing the possibility of conflicts with moving vehicles. Vehicle yielding behavior further showed that non-yielding tendencies were dominant, as 58% of vehicles did not provide priority to pedestrians. This reflects limited driver compliance and contributes to unsafe crossing conditions.

Study also demonstrated that pedestrian activity significantly affects traffic speed and flow characteristics. Vehicle

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speed reduction increased progressively from low traffic to heavy traffic conditions reaching a maximum reduction of 42.9% during congested periods. Frequent pedestrian crossings interrupted smooth vehicle movement and reduced overall traffic efficiency. Proper pedestrian facilities, controlled crossing points, improved driver awareness and effective traffic management measures are essential for enhancing pedestrian safety and maintaining efficient urban traffic operations in Sikar.

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