Children Inclusive Planning and Safety Interventions for School Zones

A THESIS

Submitted in partial fulfilment of the requirements for the award of the degree

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by

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under the supervision of

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ABSTRACT

School zones are critical urban environments that present the interaction of children, vehicles, and community movement. Children are among the most vulnerable road users in India and unsafe school zone design is one of the major contributing factors to traffic related injuries and fatalities. This study explores the concept of children-inclusive planning and safety interventions for school zones, with a focus on improving the safety, accessibility, and mobility of school-going children in urban areas. Rapid urbanization, increasing motorization, and inadequate pedestrian infrastructure have significantly increased the vulnerability of children within school environments, particularly in Indian cities. The research highlights that school zones are critical urban spaces where education, transportation, and public safety intersect, requiring dedicated planning and design interventions. The study aims to understand school zone safety from the perspectives of urban planning, transportation, infrastructure, and behavioural factors. A comprehensive review of national and international literature, Indian Roads Congress (IRC) guidelines, global best practices, and policy frameworks was undertaken to identify key parameters influencing school zone safety. The research further compares Indian provisions with global approaches to examine gaps in planning, enforcement, and implementation. The study adopts a two-phase methodology combining literature review, GIS-based spatial analysis, field surveys, traffic observations, and pedestrian assessment techniques. Bhopal city was selected as the study area, and GIS mapping was used to identify wards with high school density and accident-prone locations. Shivaji Nagar, Bhopal, was selected as the primary study site due to the concentration of educational institutions, high pedestrian movement and traffic-related safety concerns. Primary surveys involving students and teachers school authorities were conducted to understand travel behaviour, safety perception, infrastructural deficiencies, and mobility challenges. Pedestrian volume analysis, observational surveys, and infrastructure assessments revealed critical issues such as discontinuous or absent footpaths, unsafe pedestrian crossings, speeding vehicles, congestion during school hours, illegal parking, and inadequate traffic management measures. The findings highlight the lack of child-friendly infrastructure and the limited implementation of existing safety guidelines. Based on the analysis, the study proposes a set of children-inclusive planning and safety interventions focused on improving pedestrian infrastructure, traffic calming, junction organization, signage, and accessibility within school zones. The proposed interventions aim to create safer, more walkable, and inclusive environments that prioritize children as vulnerable road users. The research concludes that integrating child-centred planning principles into urban transport and road design policies is essential for promoting safe school commutes, sustainable mobility, and equitable urban development.

सारांश

स्कूल ज़ोन शहरी वातावरण के ऐसे महत्वपूर्ण हिस्से हैं जहाँ बच्चों, वाहनों और समुदाय की आवाजाही का मेल होता है। भारत में सड़क का इस्तेमाल करने वालों में बच्चे सबसे ज़्यादा जोखिम में होते हैं, और स्कूल ज़ोन का असुरक्षित डिज़ाइन ही ट्रैफ़िक से जुड़ी चोटों और मौतों के मुख्य कारणों में से एक है। यह अध्ययन स्कूल ज़ोन के लिए बच्चों को शामिल करने वाली योजना और सुरक्षा उपायों की अवधारणा की पड़ताल करता है, जिसका मुख्य उद्देश्य शहरी इलाकों में स्कूल जाने वाले बच्चों की सुरक्षा, पहुँच और आवाजाही को बेहतर बनाना है। तेज़ी से बढ़ता शहरीकरण, वाहनों की बढ़ती संख्या और पैदल चलने वालों के लिए अपर्याप्त बुनियादी ढाँचे ने स्कूल के माहौल में बच्चों के जोखिम को काफ़ी बढ़ा दिया है, खासकर भारतीय शहरों में। यह शोध इस बात पर ज़ोर देता है कि स्कूल ज़ोन शहरी जगहों के ऐसे महत्वपूर्ण हिस्से हैं जहाँ शिक्षा, परिवहन और सार्वजनिक सुरक्षा आपस में मिलते हैं; इसलिए यहाँ विशेष योजना और डिज़ाइन से जुड़े उपायों की ज़रूरत होती है। इस अध्ययन का लक्ष्य शहरी नियोजन, परिवहन, बुनियादी ढाँचे और व्यवहार से जुड़े कारकों के नज़रिए से स्कूल ज़ोन की सुरक्षा को समझना है। स्कूल ज़ोन की सुरक्षा को प्रभावित करने वाले मुख्य मापदंडों की पहचान करने के लिए राष्ट्रीय और अंतर्राष्ट्रीय साहित्य, इंडियन रोड्स कांग्रेस (IRC) के दिशा-निर्देशों, वैश्विक सर्वोत्तम प्रथाओं और नीतिगत ढाँचों की व्यापक समीक्षा की गई। यह शोध भारतीय प्रावधानों की तुलना वैश्विक दृष्टिकोणों से भी करता है, ताकि नियोजन, प्रवर्तन और कार्यान्वयन में मौजूद कमियों का पता लगाया जा सके। इस अध्ययन में दो चरणों वाली एक कार्यप्रणाली अपनाई गई है, जिसमें साहित्य की समीक्षा, GIS-आधारित स्थानिक विश्लेषण, क्षेत्रीय सर्वेक्षण, ट्रैफ़िक का अवलोकन और पैदल चलने वालों के आकलन की तकनीकों को शामिल किया गया है। अध्ययन क्षेत्र के रूप में भोपाल शहर को चुना गया, और GIS मैपिंग का इस्तेमाल करके उन वार्डों की पहचान की गई जहाँ स्कूलों की संख्या ज़्यादा है और दुर्घटनाओं का जोखिम भी अधिक है। भोपाल के शिवाजी नगर को अध्ययन के मुख्य स्थल के रूप में चुना गया, क्योंकि यहाँ शैक्षणिक संस्थानों की सघनता, पैदल चलने वालों की भारी आवाजाही और ट्रैफ़िक से जुड़ी सुरक्षा संबंधी चिंताएँ मौजूद थीं। छात्रों, शिक्षकों और स्कूल प्रशासन के साथ प्राथमिक सर्वेक्षण किए गए, ताकि उनके यात्रा व्यवहार, सुरक्षा संबंधी धारणाओं, बुनियादी ढाँचे की कमियों और आवाजाही से जुड़ी चुनौतियों को समझा जा सके। पैदल चलने वालों की संख्या का विश्लेषण, अवलोकन-आधारित सर्वेक्षण और बुनियादी ढाँचे के आकलन से कई गंभीर मुद्दे सामने आए; जैसे—अधूरे या नदारद फ़ुटपाथ, पैदल चलने वालों के लिए असुरक्षित क्रॉसिंग, तेज़ रफ़्तार वाहन, स्कूल के समय में होने वाला ट्रैफ़िक जाम, अवैध पार्किंग और ट्रैफ़िक प्रबंधन के अपर्याप्त उपाय। इन निष्कर्षों से यह बात सामने आती है कि बच्चों के अनुकूल बुनियादी ढाँचे का अभाव है और मौजूदा सुरक्षा दिशा-निर्देशों का कार्यान्वयन भी सीमित स्तर पर ही हो रहा है। इस विश्लेषण के आधार पर, यह अध्ययन बच्चों को शामिल करने वाली योजना और सुरक्षा उपायों का एक समूह प्रस्तावित करता है, जिसका मुख्य उद्देश्य स्कूल ज़ोन के भीतर पैदल चलने वालों के लिए बुनियादी ढाँचे को बेहतर बनाना, ट्रैफ़िक की गति को नियंत्रित करना, चौराहों का उचित प्रबंधन करना, संकेतक (साइनबोर्ड) लगाना और पहुँच को सुगम बनाना है। प्रस्तावित उपायों का लक्ष्य एक ऐसा सुरक्षित, पैदल चलने के अनुकूल और समावेशी वातावरण तैयार करना है, जिसमें सड़क का इस्तेमाल करने वाले जोखिमग्रस्त वर्ग के रूप में बच्चों की सुरक्षा को सर्वोच्च प्राथमिकता दी जाए। शोध का निष्कर्ष यह है कि शहरी परिवहन और सड़क डिज़ाइन नीतियों में 'बाल-केंद्रित नियोजन' के सिद्धांतों को शामिल करना, स्कूल आने-जाने को सुरक्षित बनाने, सतत गतिशीलता और न्यायसंगत शहरी विकास को बढ़ावा देने के लिए अत्यंत आवश्यक है।

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LIST OF ABBREVATIONS

CCTV - Closed-Circuit Television

GIS - Geographic Information System

iRAP - International Road Assessment Programme

IRC - Indian Roads Congress

KG - Kindergarten

LKG - Lower Kindergarten

LMIC - Low- and Middle-Income Countries

MLE - Maximum Likelihood Estimation

NCRB - National Crime Records Bureau

PCR - Predicted Collision Risk

PET - Post Encroachment Time

PSM - Pedestrian Safety Margin

RSA - Road Safety Audit

RTO - Road Traffic Outcomes

SAZ - School Access Zone

SDGs - Sustainable Development Goals

SFM - Social Force Model

SORT - Simple Online and Realtime Tracking

SPZ - School Proximal Zone

SR4S - Star Rating for Schools

SRTS - Safe Routes to School

SSMs - Surrogate Safety Measures

SWI - School Walkability Index

TTC - Time to Collision

TZ - Transition Zone

UAV - Unmanned Aerial Vehicle

UKG - Upper Kindergarten

UNICEF - United Nations Children's Fund

UT - Union Territory

VRUs - Vulnerable Road Users

WHO - World Health Organization

WRI - World Resources Institute

YOLO - You Only Look Once (Object Detection Algorithm)

QGIS - Quantum Geographic Information System

CBSE - Central Board of Secondary Education

MoRTH - Ministry of Road Transport and Highways

NIMHANS - National Institute of Mental Health and Neurosciences

CHAPTER 1

INTRODUCTION

A school zone refers to an area around school covering road network which may encompass streets / roads, bus stops, intersections and parking areas or some of them depending on the type of development and the very location of the school, figure 1 demonstrate the school zone. Specially during the school opening and closing times, the movement of higher number of children are expected within this area (Indian Roads Congress, 2023). School zones are crucial places in the city where education, transportation, and community converge. They usually involve the roads and pathways around schools that children cross daily, either on foot, by cycling, or through other motorized and non-motorized transport modes. As centre of pedestrian activity, they need special attention from urban planners, policymakers, and traffic authorities. Instead, other road environments, school zones need design considerations that prioritize vulnerable users-especially children-over car flow.



Figure 1. School Zone (Source: https://www.mot.gov.sg/what-we-do/motoring-road-network-and-infrastructure/inclusive-transport-infrastructure)

Children are one of the most vulnerable populations in road environments due to their developmental features. They have less capacity to perceive speed and distance accurately, decreased peripheral vision, and are less noticeable to drivers due to their height. They are also less capable in moving about road environments, having tendency to be more impulsive in action, and are less capable of perceiving danger (World Health Organization [WHO], 2023). When unsafe road conditions are additional to these

elements, they combine to present an excessive high risk of accidents among school-going children.

To improve the safety of school-going children while commuting to and from schools, the Indian Roads Congress (IRC) released IRC: SP:32 “Guidelines for safer commute to school” (2023, First Revision), which provides comprehensive guidelines for school zones. The guidelines explain areas such as the School Proximal Zone (SPZ), School Access Zone (SAZ), and Transition Zone. A school access zone (SAZ) may be understood as the road (s) leading to every entrance of a school, extending 100 m on either side of the school entrance (s), as explained in figure 2. If a school has more than one entrance, it will have more than one SAZ. A school proximal zone (SPZ) may be understood as the area around the school within which most students of that school will be present on roads, as they commute between home and school either by walk, cycle or public transport. Transition zone (TZ) may be understood as the predefined length of roads leading to a SPZ along which motorists should be made aware about the special nature of the approaching zone. It suggests actions like decreasing speed limits, pedestrian crossings, sidewalks, pick-up/drop-off areas, cycling infrastructure, road signage and marking. Furthermore, the guideline emphasizes stakeholder coordination which involves schools, students, parents, traffic authorities, road owning agencies (Urban Local Bodies) and other road users. They also suggest establishing a School Zone Committee for ensuring safety of school children (Indian Roads Congress, 2023)

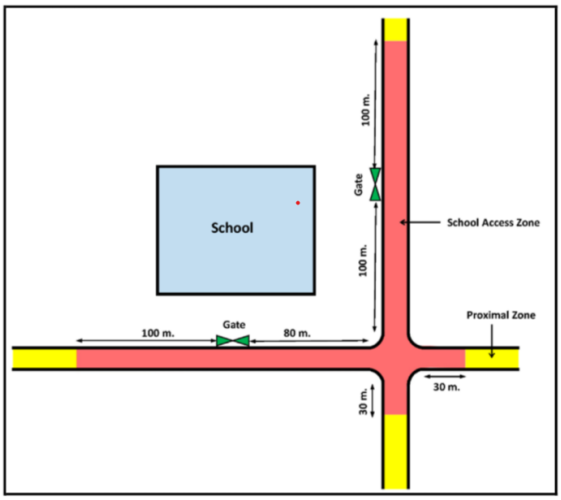


Figure 2. Typical Layout of School Access Zone located near an intersection. (IRC:SP:32, 2023)

Globally, road traffic injuries are amidst the major causes of death for children and young adults aged between 5 and 29 years (WHO, 2023). In India, this scenario is particularly true because of rapid urbanization, motorization, and poor infrastructure for non-motorized users. According National Crime Records Bureau (NCRB) everyday nearly 45 children lose their lives due to road accidents and in the year 2022, 16,443 deaths of children and adolescents were reported (Centre for Environment Education, RISE Infinity Foundation, & UNICEF, 2024).

Indian urban empirical data also reveal the magnitude of the situation. A cross-sectional survey identified that 17% of school children experienced a road traffic injury in the past year while travelling to school. Of the many travel modes, cyclists were most affected, followed by motorized two-wheeler children and walkers to school. On the other hand, school bus-traveling children were relatively safer (Tetali, Edwards, Murthy, & Roberts, 2016). All these observations indicate that the built environment in most Indian cities is insecure for active travel like cycling and walking by children.

Regardless of the severity of risks, school zone safety performance in India usually stays under standards. The Indian Roads Congress, as per IRC:103-2012, Guidelines for the Design of Pedestrian Facilities, explains detailed guidelines on creating pedestrian safe passage. The design guidelines include permanent and obstruction-free pathways with a minimum of 1.8 meters wide alongside schools, dropped kerbs accompanied by tactile paving for accessibility, and controlled pedestrian crossings at every major conflict point. They also suggest grade separation (overbridge or subways) in the event of high traffic volume, installation of guard rails to guide pedestrian flow, and deployment of appropriate signage and markings to warn drivers of school zones (Indian Roads Congress 2012).

Particularly, speed-calming devices like raised pedestrian crossings, speed humps, and rumble strips are recommended within 100 meters of school gate to promote slow speeds of vehicles. Moreover, particular areas for pick-up and drop-in of individuals that are needed to halt illegal parking and avoid congestion.

Actually, though, enforcement of the guidelines is irregular. Research in Indian cities state that most school areas have no basic facilities like continuous pedestrian paths,

zebra crossing, or clearly marked signboards. A study of 131 schools in Bengaluru and Kolar districts, revealed that only 20.8% of the nearby roadways had the safety elements they needed. Only 17% of the schools had signs for school zones, and less than 12% had signs for speed limits (Gautham, Gururaj, Nadig, Roy, & Nair, 2020). These infrastructural scarcities add up to poor enforcement. Speed limits around schools are unobserved and traffic calming devices are absent or unsustainable.

These neglection have far-reaching implications for road safety. The absence of safe infrastructure discourages walking and cycling, driving parents to rely increasingly on private cars for school journeys. This aggravates traffic congestion, increases vehicles, and reduce the potential for children to perform active travel that aids their physical and social development. In already congested cities with traffic and air pollution, both a mobility problem and a public health issue is the cause of unsafe school zones.

The importance of school zone safety thus exists at the relationship among child well-being, public health, and sustainable transport. Safeguarding schools with walking-friendly infrastructure not only prevent accident associated with children but also encourages more healthy travel habits. Additionally, safer schools promote equitable access to education, as children from lower-income household are more likely to depend on walking or bicycling. Following IRC: SP-32 standards, unite with international best practices like Safe Routes to School initiatives, offers a concrete plan for city planners and policymakers. By putting safety features in the design of roads, having compliance enforced, and uplifting community engagement, cities can turn school areas into child-friendly spaces. School zone safety is therefore not only a priority area for transportation or planning, but a matter of moral duty to secure the most vulnerable of society members.

1.1. Background

School zones are identified globally as high-risk places for children because of the unique combination of high density of pedestrians, mixed traffic, and the susceptibility of children as traffic users. Urbanization and motorization in India have increased these risks at an accelerated rate. According to NCRB, 7.0% of road accidents in urban area took place at pedestrian crossing (12,515 out 1,80,061 cases). Besides, 6.9%

(30,971 out of 4,46,768 cases) of road accidents in the country have taken place near schools, college or institutions (NCRB, 2022).

Pedestrian safety in India has historically had low planning priority. The majority of streets in urban areas have traditionally been planned to facilitate vehicular flow at the expense of pedestrian flow, resulting in discontinuous, narrow, and encroached sidewalks by vendors and parked vehicles (Osman, Nasrudin, & Abdullah, 2025). There is no formal pedestrian provision around schools, which increases the likelihood of accidents.

Having identified this lacuna, the Indian Roads Congress has created various guidelines such as IRC:103-2012 (Guidelines for Pedestrian Facilities) and IRC:67-2001 (Code of Practice for Road Signs) that stipulate standards regarding footpaths, crossings, speed calming, and school zone signage, some of the road signs commonly used in school zones shown in figure 3, figure 4, figure 5, figure 6. IRC: 103-2012 particularly suggests unbroken, obstruction-free footpaths measuring 1.8 meters wide, marked crossings for pedestrians, speed breakers, and pick-up/drop-off points outlying from school entrances to enhance child safety (IRC, 2012). IRC: 67-2001 gives extensive instruction on road signs to ensure uniformity and clarity for road users, aligning with international protocols for road signs and signals (IRC, 2001). Implementation is reported to be inconsistent in Indian cities.

The following figures illustrate some of the road signs commonly used in school zones:



Figure 3.School Ahead (IRC:67, 2001)



Figure 4. Pedestrian Crossing (IRC:67,2001)



Figure 5. Speed Hump (IRC:67, 2001)



Figure 6. Bus Stop (IRC:67 2001)

Empirical studies emphasize the extent of the problem. Tetali et al. (2016) did a cross-sectional survey of Hyderabad and reported that 17% of school-going children experienced road traffic injuries while traveling to and from school in a one-year period.

Cyclists were the ones most affected, followed by motorized two-wheeler-riding children and pedestrians. That was also the case in Bengaluru, where a study of 131 schools found that only 17% had adequate school zone signage, and less than 12% had prominently displayed speed limits (Gautham, Gururaj, Nadig, Roy, & Nair, 2020). These results shows that even with technical standards and regulations in place, school zones are still not safe because of infrastructure failure and poor enforcement of traffic rules.

Globally, child road safety programs like the Safe Routes to School (SRTS) program have resulted in successful overall interventions with a combination of infrastructure upgrades, policy enforcement, and community mobilization are possible. SRTS programs in Europe and the United States have features like enhanced sidewalks, raised crosswalks, school patrols, bike lanes, and awareness among drivers (National Centre for Safe Routes to School, 2020). Adoption of approximate multi-dimensional strategies in Indian cities may broaden current IRC guidelines and enhance school zone safety.

Excluding infrastructure, parental perceptions, traffic behaviour, and urban planning determine the safety of school zones. Research in Indian city indicates that parents often opt to use private cars rather than walking or cycling because of fear of poor road conditions, resulting in increased school area congestion (Swain, R., Oswin, P., Truelove, V., & Larue, G. S., 2023). Urban planning models now address the value of child-centred cities, stressing that secure school zones form part of sustainable urban mobility, fair access to education, and health outcomes (WHO, 2023). These highlights the necessity for detailed analysis of safety in school zones demanding physical infrastructure as well as behavioural considerations.

1.2 Need for the Study

i. **Child Road Traffic Injuries**

According to a UNICEF study, Road traffic accidents are the chief cause of death of children aged 5 to 19 years globally, claiming the lives of more than 600 adolescents and children every day (UNICEF, 2022). In India, the circumstances are the same, with a recent study conducted by UNICEF and NIMHANS that

disclosed that nearly 45 children lose their lives due to road accidents every day, and 16,443 deaths of children.

ii. **Particular Vulnerability in School Zone**

iii. School zones are especially risk-prone areas since they disclose children to vehicular traffic. School areas liable to have an abundance of child pedestrians commuting to school, crossing streets, making use of pedestrian crossings, or boarding and exiting school buses. As children's pedestrian behaviour and risk perception are still evolving, they are incapable to make quick and accurate decisions regarding vehicle speed or traffic gap, specifically in situations involving distraction or poor visibility. Child injuries also have more consequential long-term results, such as cognitive, physical, and emotional effects, which supplement burdens on families and caregivers. Research in Indian City stated that children crossed roads alone without using designated crossings, often running or crossing between parked vehicles indicating that school zones are high-risk due to unsafe pedestrian behaviour, poor infrastructure, and heavy traffic (Tiwari, Patel, Soju & Trivedi 2021). As school areas are accident hotspots, therefore, it is necessary to focus on safety interventions.

iv. Potential for High Impact Interventions

Various interventions have been widely recognizing at the global level to enhance school-zone safety, such as reduced speed limits, speed humps, pedestrian crossings with ramps, zebra crossings, school gates behind primary roads, traffic calming, safe pick-up and drop-off areas, adequate signage, improved lighting, greater visibility, and application of crossing guards. UNICEF evidence shows that the appropriate wearing of safety gear, including child restraints and helmets, can considerably reduce road injuries. For instance, child restraints reducing the chances of injury or death in accident by greater than 70% and helmets reducing the risk of head injury by more than 60% (UNICEF, n.d.). Since school zones are high-density areas of risk in which great numbers of children come into daily contact with motor traffic, their installation can affect extremely cost-efficient safety contributions. By the concentration of efforts on localized road improvements and higher enforcement in these zones, a high percentage of child injuries and deaths can be avoided.

v. Policy/Planning Weaknesses & Opportunity

Pedestrian safety among children in India is faced by planning and policy weaknesses, which enhance the vulnerability of children walking to school. Most schools lack adequate pedestrian facilities, such as safe crossings and traffic calming, to protect children from potential accident (UNICEF & NIMHANS, 2021). Moreover, lack of awareness of road safety regulations among children is an element that causes unsafe practices, from a study in Pune reporting that 17.3% of students experienced injury while commuting to school as a result of poor safety awareness (LWW Journals, 2023). Withstanding these challenges, there is potential to upgrade child road safety. Community-based interventions, like initiative by the TRAX India, highlights low-cost infrastructural improvements and school and community involvement (UNICEF & NIMHANS, 2021). Furthermore, the children can be educated and encouraged to adopt safe manners by the inclusion of road safety instruction in school curriculum (GTKP, 2022). By addressing infrastructural deficiency, strict implementation of traffic regulations, and promoting education, India can beneficially minimize road traffic hazards related to children and establish safer school environments.

1.3 Definitions

The following definitions are provided to establish a clear understanding of the key terms used in this study.

1.3.1. Child: A child is any person under the age of 18.

1.3.2. Adolescent: An adolescent is an individual in the 10-19 years age group.

1.3.3. Levels or Stages of Education in India:

Education in India follows a uniform structure of school education which is known as the 10+2 system. This system is being followed by all Indian States and Union Territories. But not all of them follow a distinct pattern as per the system.

A] Pre Primary Stage: Pre-primary education in India is provided to children between 3–6 years by Kindergarten, Play-way or Play Schools. These schools have varying terminology for different levels of classes, beginning from – Pre-Nursery, Nursery, KG, LKG (Lower Kindergarten) and UKG (Upper

Kindergarten). Most of the pre-primary education in India is provided by private schools.

B] The Primary Stage: Primary education in India offered by both private and government schools usually consist of students aged between 5 to 12 years. The duration of study in this stage is 4-5 years. Common subjects include English, Hindi, Mathematics, Environmental Science and General Knowledge. Sometimes also termed as Elementary Education, it is free in government schools but it is paid in the private schools. The Government has made elementary education compulsory for children between the age group of years 6 and 14. Most of the primary education provided by primary schools in India is imparted from class 1^{st} to class 4^{th} or 5^{th}. Some of the states/UTs which follow 1^{st} to 5^{th} class of primary education are Andhra Pradesh, Arunachal Pradesh, Bihar, Haryana, Himachal Pradesh, Jammu & Kashmir, Madhya Pradesh, Manipur, Orissa, Punjab, Chandigarh, Delhi, Karaikal and Yanam regions of Pondicherry etc. Some of the states/UTs which follow 1^{st} to 4^{th} classes of primary education are Assam, Goa, Gujarat, Karnataka, Kerala, Maharashtra, Meghalaya, Mizoram, Nagaland, Dadra & Nagar Haveli, Daman & Diu, Lakshadweep and Mahe region of Pondicherry

C] The Middle Stage: Middle stage of education covering 3-4 years of academic study is formed by 5^{th}-8^{th}class consisting of students aged between 12 to 14 years. The schools which impart education up till 8^{th} class are known with various names like – High School, Senior School. Some of the states/UTs which follow **5^{th} -7^{th} class** of middle stage are Assam, Goa, Gujarat, Karnataka, Kerala, Dadra & Nagar Haveli, Daman & Diu, Lakshadweep etc. Some of the states/UTs which follow **6^{th} -8^{th} class** of middle stage are Arunachal Pradesh, Haryana, Madhya Pradesh, Punjab, Andaman & Nicobar Islands, Chandigarh, Delhi etc.

D] The Secondary Stage: Secondary Stage of education covering 2-3 years of academic study starts with classes 8^{th}-10^{th}. consisting of students aged between 14-16 years. The schools which impart education up till 10^{th} class are known as Secondary Schools, High Schools, Senior Schools etc. Some of the states/UTs which follow **8^{th} -**10^{th} class of secondary stage are Goa, Gujarat, Karnataka, Kerala, Dadra & Nagar Haveli, Daman & Diu, Lakshadweep etc. Some of the

states/UTs which follow 9th -10th class of secondary stage are Punjab, Rajasthan, Sikkim, Tamil Nadu, Andaman & Nicobar Islands, Chandigarh, Delhi, Karaikal region of Pondicherry etc.

E] Senior Secondary Stage: Senior Secondary Education in India is of only 2 years. There is uniformity on this level of education in terms of duration and classes i.e. all the States/UTs follow this 10+2 pattern. Senior Secondary Schools in India include classes 11th to 12th. consisting students aged between 16-18 years. At this level of education students have the freedom to choose their preferred stream and subjects. They can pursue Arts, Commerce, Science (medical & non-medical). The schools which provide education up till 12th class are commonly known as Senior Secondary Schools or Higher Secondary Schools. Some universities and colleges also offer the education of these classes.

1.3 Methodology

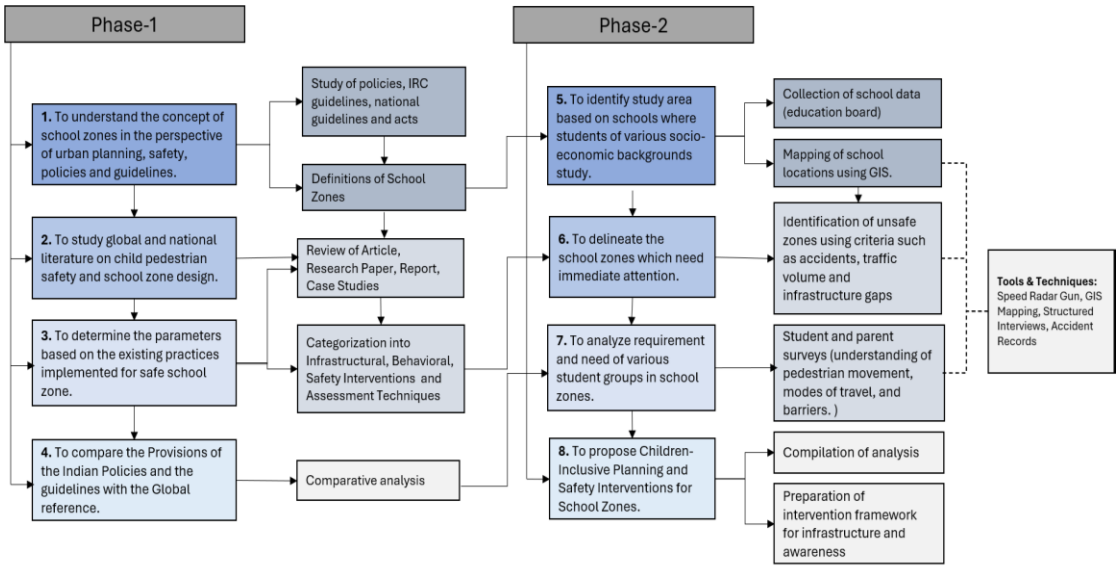


Figure 7. Methodology (Author)

The papers were gathered methodically from the Scopus database, which has an extensive collection of articles and journals that are peer-reviewed. A methodical search strategy was conducted using keywords and Boolean operators to make sure relevant studies were thoroughly covered. The search string used was: TITLE-ABS-KEY (“SCHOOL ZONE SAFETY" OR "SAFER COMMUTES TO

SCHOOL" OR "SCHOOL ZONE") AND PUBYEAR > 2019 AND PUBYEAR < 2026 AND (LIMIT-TO (SUBJAREA, "ENGI") OR LIMIT-TO (SUBJAREA, "SOCI") OR LIMIT-TO (SUBJAREA, "ENVI") OR LIMIT-TO (SUBJAREA, "DECI") OR LIMIT-TO (SUBJAREA, "PSYC")). The search string was verbalized in the title, abstract and keywords fields to find studies that intersect school zone safety with urban planning or transportation design. The search was limited to journal articles and conference papers; were required to be in English; and after identifying relevant studies published by 2020 to 2025. A total of 137 papers were accessed from the Scopus database.

The figure 7 demonstrate a two-phase methodology combining literature review and policy analysis with GIS mapping, field surveys, and data assessment to propose child-inclusive safety interventions for school zones.

Objective 1: To understand the concept of school zones in the perspective of urban planning, safety, policies and guidelines.

This objective was accomplished through a broad review of relevant Indian Roads Congress (IRC) guidelines, national road safety policies, and international guidelines. The evaluation provided conceptual clarity on the definition and scope of school zones in the broader context of urban safety and transport planning. It formed the theoretical basis for understanding how the concept of safety is manifest in the urban environment surrounding educational institutions.

Objective 2: To study global and national literature on child pedestrian safety and school zone design.

A comprehensive literature review involving academic journals, papers, technical reports, and case studies was conducted. This process led to identifying the field's focal research, strategies, and interventions concerned with child pedestrian safety and school zone design. It also exposed an ongoing gap in research and difference educated and developing countries approach for school zone safety.

Objective 3: To determine the parameters based on the existing practices implemented for safe school zone.

With the synthesis of the literature and policy review, primary parameters of school zone safety were identified and themed into four perspectives: infrastructural, behavioural, safety interventions, and assessment processes. These categories established a framework to systematically assess the strengths and weaknesses of existing school zone practices, which served as the analytical lens for the subsequent phases of the research.

Objective 4: To compare the Provisions of the Indian Policies and the guidelines with the Global reference.

This objective was achieved through a comparative analysis of Indian policies against international standards and practices. The analysis found significant progress in establishing infrastructural standards for school zones, but serious gaps remained in the behaviours and enforcement systems. The comparison indicated a clear need for integrated, and child-centered approaches that align with the global standards for pedestrian safety.

Objective 5: To identify study area based on schools where students of various Socio-Economic background study.

In the next stage, the study area will be based on the data collected from education boards and other relevant authorities. These schools will represent socio-economically diverse conditions to be able to include and represent a wide range of conditions. Geographic Information System (GIS) techniques will be used to map this information and look at the spatial distribution of schools.

Objective 6: To delineate the School Zone which need immediate attention.

Identify the School Zone that requires immediate safety action. The school zone will be identified based on GIS based mapping with accident data from the local traffic police department. This spatial analysis of the school zone will be used to identify unsafe zones and to prioritize areas that require immediate safety interventions.

Objective 7: To analyse requirement and need of various student group in School Zone.

Structured surveys and interviews will be conducted with students and their parents to learn about their travel behaviour, travel mode, and perceptions around safety.

The results will allow for the identification of barriers or challenges to mobility around School Zones for different student groups.

Objective 8: To Propose Children Inclusive Planning and Safety Interventions for School Zones.

Building from the analysed data collected in the previous objectives, children inclusive interventions will be provided, centred around two types of interventions: infrastructure improvements (traffic calming, pedestrian crossings, and signage) and behaviours awareness and policy recommendations. The result will be more informed recommendations to support equitable and safe planning for School Zones.

CHAPTER 2

LITERATURE REVIEW

Globally, road traffic injuries constitute a serious threat to public health, recognized by their inclusion in the Sustainable Development Goals (SDGs) related to health and cities (Poku-boansi et al., 2019). Children are classified as one of the most Vulnerable Road Users (VRUs) (Swami et al., 2024). Young pedestrians lack in the spatial and cognitive skills needed to safely navigate complex traffic, and they are prone to impulsive actions and risk-taking behaviours (Katoch et al., 2025). The severity of this issue is worsened in developing countries, where road traffic injuries are expected to increase as urbanization and motorization expand (Nikunj K. Kansara, 2023). In cities such as Accra, Ghana, walking remains the most used mode for commuting to school (53.7% of trips), mostly because children live within 1 km of the school However, this is usually the least safe option, as revealed by a study in Pune, India, where 17.3% of children reported a road injury during their commute to school over a 12-month period. Children who preferred to walk or used auto-rickshaws were considerably more likely to report an injury compared to those who used school buses or vans (Nikunj K. Kansara, 2023)

To mitigate road traffic injury risks, authorities worldwide implement policies that focused on reducing vehicle speed, an important factor in determining the potential severity of a collision. The usual speed limit implemented in school zones is typically low, often around 32 km/h (20 mph), supported by heavy penalties for violations. Recent studies have investigated the true effectiveness of strengthened penalty policies in areas like South Korean school zones by observing changes in driver behaviour using advanced video technology and Surrogate Safety Measurements (SSMs). These measurements included basic speed data, Pedestrian Safety Margin (PSM)-the time difference between a pedestrian crossing a conflict point and a vehicle arriving there, and Predicted Collision Risk (PCR) levels. Policy enforcement successfully resulted in average vehicle speeds aligning with the 30 km/h limit, and an increase in driver yielding behaviour was observed in the school zones. However, researchers noted that much of this compliance was merely cosmetic yielding, in simple words, drivers yielded without a safety margin that would allow for genuinely prioritization of pedestrian safety. In addition, although

danger levels (PCR) decreased inside the regulated school zones, there was an unexpected rise in danger levels in non-school zones immediately outside the designated areas, indicating that risk may be displaced by narrow policy focus(Jin et al., 2025).

The issue of reckless driving is central to school zone safety. Observational data from 11 school zones in Mumbai, India, revealed that 28.64% of observed vehicles exceeded the 30 km/h speed limit. This unsafe practice is influenced by several identifiable factors such as male drivers are 7.6% more likely to speed than females and in terms of vehicle types, especially motorcycles (11.8% likelihood), SUVs (9.7%), and minivans (5.8%), show higher probabilities of speeding. Road environment plays an important role, as the probability of speeding is 36.2% higher in unsignalized mid-blocks compared to signalized ones. Road geometry also influences behaviour as wider roads associated with increased speeding, whereas wider parking lanes actually lead to a substantial decline in speeding. Besides, the placement distance of transit infrastructure matters, as positioning transit stops more than 50 meters away from school entrances increased the probability of speeding by 29.7% (Raoniar & Perumal, 2025). Apart from speed, distracted and impatient driving is strangely common near schools. An observational study in school zones of Canada reported that nearly 20% of drivers exhibited distractions such as grooming or using touchscreens, and about one in ten engaged in unlawful handheld cell phone use despite comprehensive bans (Biondi et al., 2025).

Children's pedestrian behaviour is characterized by risk-taking and impulsivity, and requires targeted educational interventions. These risky behaviours increase according to social context and time of day like whether children are travelling to school alone or with adults in the morning, in the afternoon, the majority (96%) walk with their peers, resulting to significantly riskier crossings as study revealed 74% of riskiest observed crossings occurred in these afternoon period (Katoch et al., 2025). Effective road safety education (RSE) for young children (aged four to eight) must prioritize skill acquisition over mere knowledge transfer and focus on specific, frequent dangers, such as a person emerging from behind parked cars. Classroom's only learning models are generally ineffective, and skills training cannot fully complement knowledge acquisition until children reach about nine or ten years old (Thein et al.,1993). Educational resources

must be tailored to local contexts, as shown by the development and evaluation of the 'Safe Feet' RSE resource in Pune, India, for six-year-olds. The program, which used practical, participatory activities, demonstrated a marked increase in children's knowledge of safe walking rules and traffic danger concepts. Significantly, the study deliberately chose not to teach children to cross roads independently or use zebra crossings, acknowledging that local traffic conditions rendered these behaviours too dangerous for young students (Sayer et al., n.d.).

The degree of safety for children is tied to the quality and availability of the built environments or infrastructure. In low-to-middle-income countries, the presence of poor infrastructure (e.g. poorly maintained sidewalks, lack of guardrails, inadequate place for pedestrians) contributes to risk (Swami et al., 2024). In a survey of authorities in Vietnam, safe road infrastructure was rated as the only improvement that was expected regarding traffic safety (Ngoc & Hung, 2020). In order to identify and improve these conditions in a structured way, the school walkability index (SWI) was used as one method. The GIS-based SWI can determine the characteristics of road segments within a pedestrian catchment area taken as 3-to-15-minute walking times considering if there was no sidewalk, if the sidewalk was in good condition, and if there were physical barriers. An application of the SWI in Parma, Italy indicated particularly low scores of walkability in outer urban or obsolete residential regions where the sidewalk was unpaved or narrow (Rossetti et al., 2024).

To further illustrate the role of design, microscopic simulation models (e.g., Social Force Model (SFM)) can measure the safety impact of a design proposal before it is in place. A simulation study of a school zone in Delhi, India, validated the measured effects from specific interventions like sidewalk width increased from 2.5 meters to 3.5 meters results in 44.4% reduction in pedestrian-vehicular conflicts. Traffic calming measures like speed bumps and improved signage resulted in an average decrease in vehicular speeds of 26% from 32 km/h to 23.8 km/h. In total, these studies indicate engineered solutions can provide more quantifiable safety benefits (Swami et al., 2024). Related to this are road safety audits (RSAs), completed at the pre-opening stage of a project, that can provide necessary safety identification of hazards (Hildebrand et al., 2012). Road

safety audits tend to focus on hazards that are associated with improper missing on-site signage, grading, and that related to vulnerable road users with pathways.

At last, the count of risk related knowledge must also consider spatial distributions of accidents or non-traffic safety issues The authors conducted a study to classify school zones in Seoul, South Korea based on the location of accident hotspots relative to the 300-meter radius from school area which noted accidents occurring inside the zone vs. outside and reported on four types of risk zones. This classification provided the basis for policy intervention, either to expand the school zone boundary, Type B zone includes where accidents were clustered outside or Type C zone include where accidents were clustered inside. In particular, Type D was considered the most dangerous type, with accidents clustered in both the inside the zone and outside, and should be prioritized for inspections and safety improvements (Chun et al., 2024). The study also discussed that non-traffic safety issues and non-traffic safety influences children and the urban environment. Specifically, research found a unique U-shaped relationship between pedestrian volume and the fear of crime by it could either be attributed to space factors (e.g. darkness and isolation) or human factors (e.g. peer bullying, violence from strangers & others) (Kirk et al., 2023). This confirms that effective comprehensive safety strategies must take into account both vehicle-related issues and social/environmental threats.

To sum up, the literature emphasizes that child pedestrian safety involves a multi-faceted approach where Engineering, Education, Enforcement and Evaluation must work together (Swami et al., 2024). While legislative enforcement can elicit rapid behavioural change like speed reduction, some limitations exist, such as cosmetic yielding and risk displacement, which requires thorough evaluation and spatial follow-up (Jin et al., 2025). Overall, consistent and frequent safety measures with a more sophisticated spatial modelling capturing complex interactions will be vital for meaningful work towards equitable and child-centred sustainable urban mobility solutions(Katoch et al., 2025).

Table 1. A Comparative analysis of School Zone Safety studies across Global Site (Author)

Year	Paper	Location	Focus	Key Findings	Research Gaps	Future Research
2020	Road Safety for School Zones in	Greece	The research analysed road safety	Most parents in Xanthi drive their	The paper is primarily descriptive	Suggested to include empirical

	Medium-Sized Cities		in school zones with an emphasis on parental transport choices, traffic density, and pedestrian accessibility.	children to school, increasing congestion near school gates. Lack of walking infrastructure and inconsistent enforcement reduce safety.	and lacks empirical measurement of safety outcomes.	crash data and long-term monitoring of interventio n impacts.
2021	Does Proximity to School Still Matter Once Access to Your Preferred School Zone Has Already Been Secured? (Huang & Dall, 2021)	Aucklan d, New Zealand	Relationship between property values and proximity to schools within enrolment zones	Proximity affects house prices even within zones; closer proximity increases prices in prestigious zones but decreases in less prestigious ones.	Limited study on intra-zone proximity effects; need to include variables like air quality and income.	Identify factors that make school proximity an amenity or disamenity to improve urban design.
2023	Children's and parents' perceptions on safe road crossing near schools (Swain et al., 2024)	Australia	The study investigated three main research questions regarding children's and parents' perceptions of safe road crossing and influencing factors.	Perceptions of road safety were a significant predictor of safe crossing behaviour. Environmental design features such as crosswalk markings and signal timing affected perceived safety.	Limited to perceptual data; actual behavioural validation not conducted.	Future research could integrate objective behavioura l observatio n to compleme nt perception-based findings.
2023	Effects of tougher school zone laws on road traffic injuries: Evidence	South Korea	The study evaluated the effectiveness of new school zone protection	The study found that the new, tougher school zone laws led to a statistically significant	The author identified several limitations and the need for longer-term analysis to	Future work should evaluate the interaction between

	from South Korea (Eun, 2023)		laws and their impact on child pedestrian injuries.	decrease in child pedestrian injuries in urban areas.	assess behavioural adaptation.	law enforcement, infrastructure, and community awareness in sustaining safety gains.
2023	The relationship between children's fear of crime and pedestrian volume in school zones (Kirk et al., 2023)	Seoul, South Korea	Investigated how pedestrian volume (as a proxy for natural surveillance) affects children's fear of crime in school zones.	Found a U-shaped relationship: fear was highest in low and high pedestrian volume areas and lowest in moderate ones; causes differed—darkness/few people in low-volume areas, bullying/strangers in high-volume areas; no major difference between residential types.	Lack of child-focused research on fear of crime; small sample (2 schools) limits generalisability; did not measure intensity of fear or safe spaces.	Use GPS for accurate mapping, expand sample size, include fear intensity and safe areas, develop distinct safety strategies for low- and high-volume zones.
2024	Towards More Walkable Streets: An Assessment Method Applied to School Areas in Parma (Rossetti et al., 2024)	Parma, Italy	Development of a School Walkability Index (SWI) to assess pedestrian friendliness around schools	The SWI identified low walkability zones; sidewalks often missing or obstructed, especially in 10–15-minute zones; peripheral schools showed poorer infrastructure.	Method did not account for road segment length and excluded historical centre schools.	Enhance SWI by including segment length and integrating pupil perceptions through surveys.

2024	Modelling Speed Behaviour of Vehicles in School Zones Under the Impact of Motorcycle-Dominated Societies (Tan et al., 2024)	Pleiku City, Vietnam	Modelling vehicle free-flow speed in school zones before and after 30 kph limit implementation	Higher roadside activity lowers speed; wider roads increase speed; motorcycles had highest average speed (~80 kph); many vehicles exceeded limits; MLE effectively modelled speed distribution.	Study limited to one city; excluded factors like intersections and road geometry; lacked long-term analysis.	Assess long-term effects of speed limits and test additional calming measures, especially for wider roads.
2025	Do enhanced school zone policies improve pedestrians' safety? A deep learning-based case study of Osan City, South Korea. (Jin et al., 2025)	South Korea	Evaluated strengthened school zone penalty policy using CCTV-based deep learning to assess pedestrian–vehicle interactions.	Policy reduced vehicle speeds and increased yielding; mixed effects on collision risk with better outcomes in school zones.	The CCTV could not distinguish child vs. adult pedestrians; limited to six sites.	Improve algorithm accuracy, expand study scope, and examine behavioural responses.
2025	Factors Affecting Driver Speeding Behaviour in Mumbai School Zones (Raonia r & Perumal, 2025)	Mumbai, India	Analysed demographic, vehicular, and environmental factors influencing speeding (>30 km/h) in school zones	28.64% of vehicles exceeded limit; male and younger drivers more likely to speed; motorcycles and SUVs most prone; arterial roads and wider carriageways increased speeding likelihood; wider parking	Limited data coverage (only school hours, 11 sites); excluded factors like traffic volume, weather, or driver state.	Comparative studies on zones with traffic calming, and broader temporal data collection recommended.

				lanes and signalised mid-blocks reduced speeding.		

The table 1 demonstrates the studies reviewed from across the globe, presented in a chronological manner. The table provide insights about how different regions and site respond to problems of school zone safety.

2.1. Parameters of School Zone Safety

Figure 8. demonstrate the parameters of School Zone Safety.

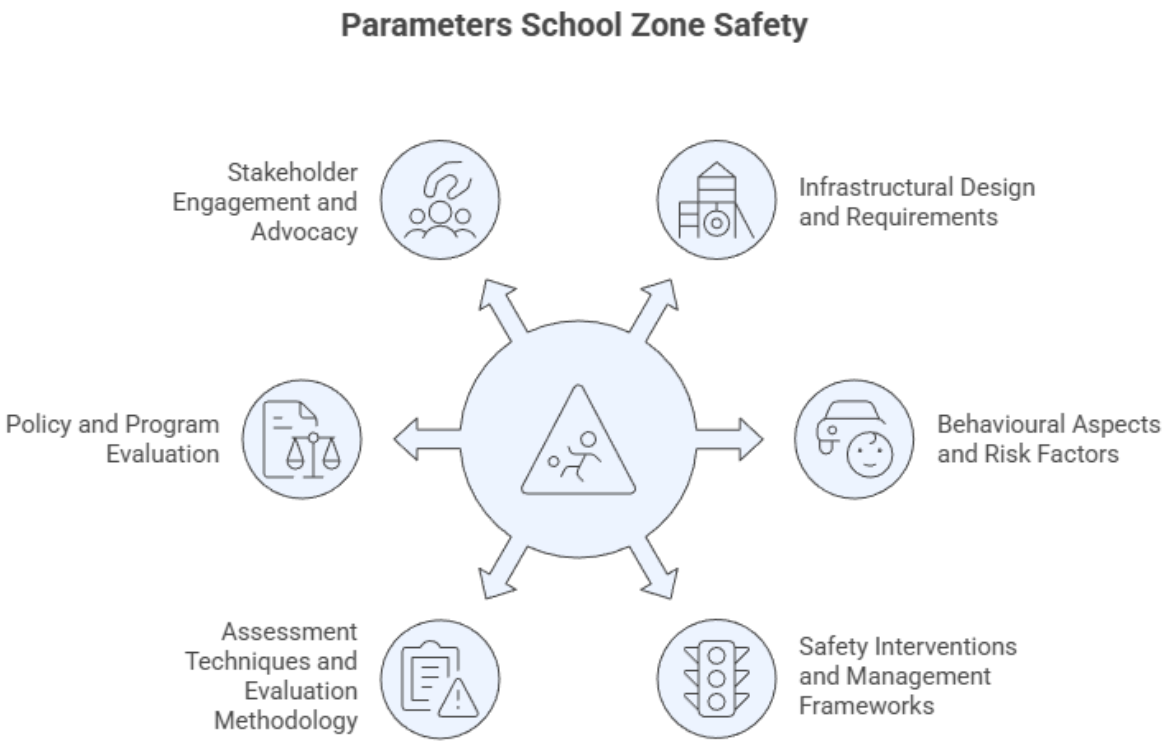


Figure 8. Parameters of School Zone Safety (Author)

2.1.1. Infrastructural Design and Requirements

This category includes a variety of physical components, road geometry and built environment characteristics that are connected to school zone safety:

i. **Essential Facilities:** Elements of infrastructure that are advantageous to include in safety strategies are sidewalks, crosswalks, bicycle facilities, and parking

(Yuan & Ermagun, 2025). These elements commonly identified as missing or necessary across the globe and in India are pedestrian crossings, crosswalks, guardrails, traffic signs, traffic management measures, and calming measures (Swami et al., 2024).

ii. **Geometric Parameters:** This covers the lane width, shoulders, median, kerbs, horizontal alignment and vertical alignment. Research states specific attributes such as road width significantly impact safety and driver behaviour, a study in India revealed that, sidewalk width increased from 2.5 meters to 3.5 meters, significantly decreased pedestrian-vehicular conflicts (Swami et al., 2024).

iii. **Traffic Calming Measures (Physical):** These improvements of a physical nature are aimed at encouraging speed moderation, for example: speed bump, speed humps, platforms, speed cushions, rumble strips, and textured pavement. India offers guidelines for a variety of active (design-enforced), and passive (law-enforced) calming measures (IRC,2018).

iv. **Universal Design Elements**: Walkability-related elements from a universal design view contain provision for ramps, continuity on sidewalks, and surface conditions (Rossetti et al., 2024).

v. **Signage and Markings:** This included speed feedback, flashing beacons, school symbols, and speed limit markings, and pedestrian crossovers (Rothman et al., 2022). Indian guidelines (IRC) specify the design and location requirements for mandatory, cautionary, and informatory signs (IRC, 2001).

2.1.2. Behavioural Aspects and Risk Factors

This category emphasizes the behaviours, perceptions, and demographic characteristics that affect road safety for children and drivers:

i. **Child Pedestrian Behaviour:** Children have limited cognitive skills and are prone to impulsive behaviours. Risk-taking behaviours increase with age and peer influence, especially during the afternoon pick-up time (Katoch et al., 2025). Casual observations of risky behaviours, for example, include jay walking, crossing at places that are not designated for crossing or playing while crossing the road (Poku-boansi et al., 2019).

ii. **Driver Behaviour:** Distracted or impatient driving behaviour are top contributors to crashes (Biondi et al., 2025).
    a. Approximately 20% of drivers observed in Canadian school zones demonstrated distracting and/or impatient driving (Biondi et al., 2025).
    b. Behaviours include hand-held cell phone use like texting or talking, manipulating a vehicle's touchscreen, grooming, eating, and smoking (Biondi et al., 2025).
    c. Drivers of large vehicles such as pick-up trucks, large SUVs, and large trucks showed a greater likelihood of distracting and/or impatient driving than drivers of smaller vehicles (Biondi et al., 2025).
    d. In Mumbai, 28.64% of vehicles exceeded a speed limit of 30 km/h. Male drivers are 7.6% more likely to speed compared to female drivers (Raoniar & Perumal, 2025).

iii. **Socioeconomic Factors:** Children from low-income homes are more likely to rely on walking or cycling also known as active travel, through environments that do not have important infrastructure to fully protect them. Relying on active travel forces children to be exposed to risk (Poku-boansi et al., 2019) (Swami et al., 2024).

iv. **Perception of Safety:** Students attending schools with better pedestrian infrastructure and control devices perceived lower risks (Katoch et al., 2025). Students feared crime in both areas of low and high pedestrian numbers. In areas of low pedestrian volume there was fear driven by darkness or fewer people. In high pedestrian areas, fear stemmed from strangers or peers who bullied them (Kirk et al., 2023).

2.1.3. Safety Interventions and Management Frameworks

This category describes the systems, policies, and educational or regulatory approaches to improve safety:

i. **Global Safety Frameworks:** Safety efforts are supported by the Sustainable Development Goals (SDGs) (Goals 3: Good Health and well-being and Goal 11: Sustainable Cities and Communities) and the principle of Vision Zero, which

transfers responsibility for safety from the individual user to the system level (Poku-boansi et al., 2019) (Rothman et al., 2022).

ii. **The "E" Frameworks:** Programs often rely on a multidisciplinary campaign, such as the "4 E's" (Engineering, Education, Enforcement, Encouragement) (Ngoc & Hung, 2020), or the extended "6 E Framework," which is articulated in the U.S. Safe Routes to School (SRTS) program which states Engagement, Equity, Engineering, Encouragement, Education, and Evaluation (Yuan & Ermagun, 2025).

iii. **Education and Encouragement**: These approaches incorporate community awareness campaigns, educational programs for traffic safety, and cycling classes (Yuan & Ermagun, 2025). Education should engage both children and their parents as it is essential for developing safer behaviours (Swami et al., 2024).

iv. **Enforcement and Penalties:** In this group, the focus is on the police campaign to encourage compliance for offending behaviours, such as speeding and entering an intersection on a red signal (Ngoc & Hung, 2020). The overall effect of harsher punishments is mixed. In South Korea, stricter penalty policies did not result in a statistically significant change in the rates of Road Traffic Outcomes (RTO) of children ages 0-12. Other studies have shown that the conviction of punishment is more salient than the severity of the punishment (Eun, 2023).

v. **Supervision:** Interventions include the implementation of school guards. The implementation of a school guard program resulted in a marked increase of driver yielding behaviour in Kampala, Uganda (Katoch et al., 2025).

2.1.4. Assessment Techniques and Evaluation Methodology

This category includes the tools, data sources, and analytical methods that are used to measure risk, evaluate interventions, and prioritize actions for improvement:

i. **Crash Data and Hotspot Analysis:** Studies have become reliant on historical crash data, with availability and reliability still being issues of concern, especially in LMIC (Low-Middle Income Countries) (Katoch et al., 2025). Hotspot analysis and spatial autocorrelation are utilized to determine areas of high-risk using GIS tools. In Seoul, determining school zones involved classifying them into four types, or categories such as Type A, B, C, and D, based on accidents occurring

inside and outside the zone, which helped to define conditions for policy responses (Chun et al., 2024).

ii. **Surrogate Safety Measures (SSMs):** These are proactive measures that estimate the possible of a collision without relying solely on the infrequent data of crashes (Jin et al., 2025). Some of the SSMs include:

   a. Time to Collision (TTC) and Post Encroachment Time (PET).
   b. Pedestrian Safety Margins (PSM).
   c. Predicted Collision Risk (PCR) level, which is calculated from predicting a collision by predicting pedestrian and vehicle trajectories using deep learning model (Jin et al., 2025).

iii. **Advanced Data Collection Technology:** Video footage is designed to automatically extract road user behaviours including trajectories through either computer vision techniques or deep learning algorithms like YOLO and SORT for larger scale cooking of the data (Jin et al., 2025). Data collection through Unmanned Aerial Vehicles (UAVs) also known as drones (Katoch et al., 2025).

iv. **Simulation and Modelling:**

   a. Microscopic simulation tools like PTV Vissim/Viswalk, using the Social Force Model (SFM) are used to pre-test the impact of geometric and infrastructural changes such as widening sidewalks and adding speed bumps prior to actual implementation (Swami et al., 2024).
   b. The Maximum Likelihood Estimation (MLE) method is employed to model the probability density function of vehicle speed in school zones (Tan et al., 2024).

v. **Walkability and Risk Assessment Tools:**

   a. The Star Rating for Schools (SR4S) tool is a tool based on evidence, used worldwide in the countries like Indonesia, Malaysia, Philippines to measure and communicate road design star ratings from1-star least safe to 5-star safest, which is part of the International Road Assessment Programme (iRAP) (Ellizar et al., 2023).
   b. School Walkability Index (SWI) is a GIS-based methodology used to assess walkability in defined pedestrian catchment areas around the school which has been adopted in Parma, Italy (Rossetti et al., 2024).

vi. **Safety Audit:** The Road Safety Audit (RSA) is a formal and independent assessment of road performance which expands the terms of reference to include any road user, not just vehicle traffic and involves a comprehensive safety review to help identify potential safety issues during the design process (IRC, 2012)

2.1.5. Policy and Program Evaluation

This section deals with the efficiency of safety programs, as well as their respective structural contexts:

i. **Policy Effectiveness Gaps:** Despite significant investment in programs like SRTS in the US, national trends show alarming rates of obesity, declining active travel, and continued school-transport-related crashes. This suggests SRTS implementation often falls short of expectations due to unstable program support, lack of a reliable assessment system, and the absence of consistent feedback (Yuan & Ermagun, 2025).

ii. **Implementation Imbalance:** A consistent global trend is that most funding goes toward infrastructure improvements (Engineering), while non-infrastructure efforts (Education, Encouragement) often receive smaller shares, limiting sustained behaviour change (Swami et al., 2024).

iii. **Spillover Effect:** Strengthening penalties and focusing interventions specifically within school zones can have unintended negative consequences, such as an unexpected increase in danger levels in non-school zones (Jin et al., 2025).

iv. **Context Sensitivity:** Effective programs require a context-sensitive approach tailored to local conditions, as effectiveness varies widely based on local capacity depending upon urban area and rural areas (Yuan & Ermagun, 2025).

2.1.6. Stakeholder Engagement and Advocacy

i. **Multistakeholder Involvement:** Successful safety initiatives depend on consistent leadership, cooperation and accountability among stakeholders (Rothman et al., 2022).

ii. **Community Participation:** Input from the school community which involve parents, students, staff, faculty and advocacy groups is crucial for identifying

safety issues and developing appropriate interventions. Stakeholder surveys are a key component of assessment protocols (Swami et al., 2024).

iii. **Youth Participation:** Engaging youth in identifying road problems and conducting assessments using SR4S is a meaningful technique for road safety planning, providing a powerful basis for planned advocacy with the government (Ellizar et al., 2023).

iv. **Citizens as Guardians:** Community can act as guardians of the existing infrastructure and make citizens aware about urban development projects(Swami et al., 2024).

2.2. Comparative Analysis

2.2.1. Policy Framework and Institutional Coordination

Indian Context: India's school-zone safety policies are guided primarily through advisory technical codes rather than statutory mandates. The Indian Roads Congress IRC: SP: 32 (Guidelines for Safer commute to schools). Similarly, IRC: 103-2012 (Guidelines for the design of pedestrian facilities) addresses including a dedicated subsection on which recommends providing safe crossings, continuous footpaths, guard rails, and speed calming (IRC, 2012) (IRC, 2023). Despite these frameworks, there is no unified "Safe School Commute Policy" binding multiple agencies. Implementation remains fragmented between municipal engineering departments, traffic police, education departments, and NGOs. The Ministry of Road Transport and Highways periodically issue advisories promoting school safety audits and signages, but without statutory enforcement, outcomes remain uneven.

Global Context: The United States Safe Routes to School Program, overseen by the Federal Highway Administration, requires states to develop a safety program coordinator and allocate funding while combining educational and awareness activities, law enforcement initiatives, and engineering strategies (Yuan & Ermagun, 2025). Sweden's Vision Zero Policy is a safety framework policy that has specified school zone safety measures focusing on speed management, crossing safety, and collective responsibilities of stakeholders, which includes mandates in its statutory road safety policy for 30 km/h zones (Vision Zero Network, n.d.).

Comparison: India has a guideline-based approach that is not as robust as the institutional and legislative components of global functions. Developing a unified child mobility policy in conjunction with IRC design codes would provide a policy vehicle to enhance the gap between policy intentions and realities.

2.2.2. Speed Management and Design Speed Standards

Global Context: Worldwide, low speed limits are very important because colliding with a person at a speed of 50kph is five times more likely to be fatal than at 30kph (Tan et al., 2024). Speed limits for school zones are often set at 30 km/h in South Korea and Spain or 40 km/h in Canada (Jin et al., 2025) (Biondi et al., 2025) (Raoniar & Perumal, 2025). However, compliance is a problem, for example, in Canada, many studies have found that a considerable number of cars are speeding even after an intervention (Tan et al., 2024).

Indian Context: The speed limit in school zones in India is essentially 30 km/h (IRC: SP:32 ,2023). Speeding is quite common, and in Mumbai school zones, 28.64% of vehicles are over the speed limit. Road geometry has an important impact on speed, with wider roads resulting in greater speed (Raoniar & Perumal, 2025).

Comparison: Both India and the international consensus call for extremely low speed limits near schools (30-40 km/h). However, drivers in India are much more challenged with compliance, where speeding is a key element of accident risk (Raoniar & Perumal, 2025). International experience shows that high-tech tools like automated photo enforcement can be very effective in reducing speeding violations (e.g., a nearly 50% reduction in one US study) (Jin et al., 2025).

2.2.3. Infrastructural Design and Safe System Principles

Global Context: The Safe System approach mandates adapting the transport system to account for human limitations, meaning the infrastructure and vehicles must adapt to suit people (Vision Zero, 2025). Developed regions focus on designing infrastructure to minimize the severity of crashes. In some African cities like Accra, there is a recognized lack of child-friendly transport infrastructure, and in Malaysian schools, pedestrian facilities are frequently inadequate, poorly maintained, and obstructed (Poku-boansi et al., 2019) (Osman et al., 2025).

Indian Context: In India, the infrastructure gap is significant; for example, a walkability inventory, which took place in South Delhi, showed that many school zones, lack essential infrastructure for pedestrian facilitation, such as sidewalks and pedestrian guardrails. Microscopic simulation modelling was used to establish the implications of research intervention design by either providing wider sidewalks at 2.5 meters to 3.5 meters resulted in a 44.4% reduction in pedestrian-vehicular conflicts, along with an average 26 % decrease in average vehicular speeds from 32 km/h to 23.8 km/h.(Swami et al., 2024).

Comparison: Although high-income countries invest a lot of money in replacing and enhancing already-safe infrastructure, India and most LMICs (Low-Middle Income countries) encounter challenges related to the absence or insufficient level of basic pedestrian facilities (Osman et al., 2025). “Engineering” type solutions like modifying the physical environment was perceived as an expected improvement to traffic safety in LMICs like Vietnam (Ngoc & Hung, 2020).

2.2.4. Data Collection, GIS Mapping and Prioritisation

Global Context: Global safety assessments increasingly use proactive methods. South Korea employs advanced techniques like computer vision and deep learning algorithms to extract road user behaviour from video footage. This data generates Surrogate Safety Measures (SSMs), such as Predicted Collision Risk (PCR) level and Pedestrian Safety Margins (PSM), which predict potential risk without relying on historical crashes (Jin et al., 2025). GIS methodologies are also used, such as calculating the School Walkability Index (SWI) based on walking catchment areas in Italy (Rossetti et al., 2024).

Indian Context: Low-middle-income countries (LMICs) like India often have poorly maintained accident data and therefore the combination of GIS tools and models can help identify accident hotspots in order to address safety interventions (Katoch et al., 2025). A GIS mapping study was conducted in South Delhi to conduct a walkability inventory study and identify deficiencies in walking infrastructure (Swami et al., 2024).

Comparison: The global trend, particularly in South Korea, involves moving toward predictive safety evaluation using cutting-edge technology (SSMs, computer vision) (Jin et al., 2025). India utilizes GIS for mapping and visualization, aiming to compensate for

data sparsity and identify foundational infrastructure gaps (Swami et al., 2024). South Korea also uses spatial analysis to categorize school zones (Types A to D) to guide improvements and expansions (Chun et al., 2024).

2.2.5. Enforcement, Technology and Monitoring

Global Context: South Korea has passed new laws in March 2020 that increased penalties and required automated enforcement devices. However, the added penalties were not related to finding a statistically significant decrease in road traffic outcome (RTO) for children. This suggests that higher penalties may not be sufficient (Eun, 2023). Enforcement must be timely and effective (Ngoc & Hung, 2020). Automated technologies can monitor behaviours such as speeding or yielded to assess the efficacy of policies (Jin et al., 2025).

Indian Context: Enforcement across India is often uncoordinated. An example study in Mumbai found only 1 of the 11 school zones had a speed limit sign, and at times, roads managing speed measures (such as bumps) have been even less effective, complying with minimum guidelines or not placed closer to the crosswalk, which would have been effective (Raoniar & Perumal, 2025).

Comparison: India faces challenges in implementing basic enforcement measures and complying with design guidelines (e.g., IRC specifications for signs) (Raoniar & Perumal, 2025). Globally, the focus is shifting to measuring policy impact using advanced technology (like PCR and PSM levels in South Korea) (Jin et al., 2025). Both contexts, however, support the finding that increasing the certainty of apprehension and consistent enforcement is more crucial than merely increasing the severity of punishment (Eun, 2023).

2.2.6. Community Participation and Multistakeholder Processes

Global Context: Achieving safety goals requires sustained leadership and collaboration among a diverse group of stakeholders, including community members, to ensure Vision Zero goals are met (Vision Zero, n.d.). The multi-criteria assessment model used in Vietnam for traffic management measures emphasizes the role of the general public, who are the main beneficiaries, in assessing the appropriateness of solutions (Ngoc & Hung,

2020). Successfully transforming streets, such as through “play streets” often originates from citizen initiatives (Rossetti et al., 2024).

Indian Context: Community input is integral to safety assessment. The study in South Delhi employed a stakeholder perception survey involving faculty, parents, and children to gather concerns about pedestrian safety and walkability. Stakeholders should be aware citizens and act as “guardians of the present infrastructure”. Coordination between agencies, planners, and stakeholders is considered essential for improving walkability (Swami et al., 2024).

Comparison: The value of multi-stakeholder processes is universally accepted (Vision Zero, n.d.). While the global Vision Zero framework formalizes this collaboration for accountability and system change, Indian studies actively integrate community feedback early in the assessment phase to address local concerns and promote awareness (Swami et al., 2024).

2.3. Desk Example

2.3.1. Desk Example-1: Toronto, Canada.

A] Introduction

The Pilot study conducted from 2017 to 2019, was to assess school safety zone built environment interventions, which the research team created as part of the Vision Zero Road Safety Plan. Interventions near schools were identified, as this was a critical area of focus in Toronto. The density of child pedestrian motor vehicle collisions was greatest in school zones, especially fatal collisions. The overall aim of the Vision Zero interventions was to promote safe active school transportation (AST) for children and increased active transportation by causing a reduction in speeds. The research focused on the impact of the intervention package on three primary outcomes: (1) driver speeds; (2) active school transportation (AST), and (3) dangerous driving. Given that collisions are infrequent events, they focused on driver speed as the most important predictor of pedestrian collision risk and severity. They also measured AST as it contributes to various health, community, and environmental outcomes (Rothman et al., 2022).

B] Methodology

A pre-post quasi-experimental controlled design was used. This study examined 34 intervention schools that underwent Vision Zero school safety zone-built environment interventions in the years 2017 to 2019 and 45 matched control schools that did not receive the intervention during the study period shown above. Intervention schools were selected first based on historical rates of pedestrian motor vehicle collisions involving school-aged children living within 1.6 km radius of each school and the proportion of students who lived within walking distance of each school. Control and intervention schools were matched on school level (e.g., elementary, high school) and socioeconomic status (Rothman et al., 2022).

C] Proposed Interventions

The package of built environment interventions included several components, primarily focused on indicators and signs, as shown in figure 9, figure 10, figure 11 and figure 12, rather than physical infrastructure. The interventions included:

i. Speed feedback signs (Watch Your Speed Boards).



Figure 9. Watch your speed board. (Pilot study to evaluate school safety zone built environment interventions,2021)

ii. Flashing beacons (most frequently installed, totalling 103).



Figure 10. Flashing Beacons. (Pilot study to evaluate school safety zone built environment interventions,2021)

iii. **'School' and speed limit markings (Speed symbols and School symbols).**



Figure 11. School Symbol. (Pilot study to evaluate school safety zone built environment interventions,2021)

iv. Other pavement markings (e.g., zebra bars, crosswalk lines).

A total of 357 interventions were installed across the 34 schools. Crucially, the implemented interventions were *restricted to school zone and speed indicators* (lines and signs), lacking physical traffic calming measures or additional enforcement.



Figure 12. Pavement Marking. (Pilot study to evaluate school safety zone built environment interventions,2021)

D] Outcome Measurement

i. Driver Speed: Measured between 07:00 and 18:00 using pneumatic speed tubes at the main frontage of the school. Results included the percentage of drivers exceeding the posted speed limit, the percentage of drivers exceeding 30 km/hour (the designated parameter for pedestrian safety purposes), and the 85th percentile speed.

ii. AST: Trained university students observed and counted children arriving by walking, biking, scooter, or rollerblading during the morning drop-off time.

iii. Dangerous Driving: Observations during morning drop-off at 21 intervention schools and 45 control schools. Dangerous behaviours were observed and

recorded, such as: cars blocking pedestrians, U-turns, double parking, and texting/talking on the phone while driving.

E] Key Findings

i. **Context of Speed Limits and Initial Speeding:** Before the interventions were instituted, speeding in school zones was a key concern. The observations found that a large proportion of drivers were speeding, which is a threat to child pedestrian safety, in school zones. Most schools were (82%) located on roads with legally posted speed limits above 30 km/hour (km/h), most frontages were posted at 40 km/h (58%), and some were at or above 50 km/h (23%). This environment contributed to unsafe driving behaviour, as nearly half of all drivers were recorded traveling above the posted limits. Specifically, in intervention schools, approximately 71% of drivers were recorded at speeds above 30 km/h, and the 85th percentile speed exceeded 47 km/h, indicating that many drivers were travelling at extreme speeds that were not safe in school zones.

ii. **Effect on Driver Speed:** The built environment intervention did not yield marked changes in driver speed behaviour around schools. Although a statistically significant decline was noted in average proportion of vehicles exceeding posted speed limits at intervention schools, from 44% before the built intervention to 40% after, this represented a 21% decrease in the odds of drivers exceeding the speed limit. However, this change was limited in scope as the decline represented schools with posted speed limits of 40 km/hour. The mean proportion of vehicles travelling over 30 km/hour did not change from 71% after the intervention and the speed of the 85th percentile did not change after the intervention. In addition, control schools also did not have any significant difference in any of the measures of speed behaviour, confirming a localized and limited effect of the intervention package.

iii. **Effect on Active School Transportation (AST):** The results show a positive trend towards more active school travel (AST) after the intervention. In the intervention group, the proportion of students who travelled to school using AST increased from 59% before the intervention to 64% afterwards. This indicates a small increase in walking or biking to school. Therefore, the unadjusted odds of

students using an active school travel mode increased by 22%, this shows a shift towards more active school transport, though it's not statistically significant. The control group did not show any change in the levels of AST with the participation rate of 65% before and after the intervention. Certainly, this comparison shows that while the Intervention Group was able to encourage a slightly greater uptake of active travel modes, in general, the impact of the intervention was modest overall.

iv. **Effect on Dangerous Driving:** Before the intervention, dangerous driving behaviour was alarmingly widespread, occurring at 97% of all observed schools. Following the implementation of interventions, notable reductions in such behaviours were recorded at intervention schools. Specifically, six out of the nine measured forms of dangerous driving showed a decline, indicating some improvement in driver conduct near school zones. The most substantial reduction was seen in instances of drivers backing up dangerously, which decreased from 90% to 62% of observed schools, marking a significant behavioural shift. Interestingly, similar decreases across six of the nine dangerous driving behaviours were also noted in control schools, suggesting that broader factors beyond the implemented interventions may have influenced these improvements (Rothman et al., 2022)..

F] Conclusions and Policy Implications

The pilot study demonstrated that the initial package of built environment interventions in Toronto's School Safety Zones had modest effects on speed reduction, AST, and dangerous driving. The findings emphasize that the interventions implemented were restricted to lines and signs without physical traffic calming or additional enforcement were insufficient to achieve a meaningful speed reduction around schools. The high proportion of drivers traveling above 30 km/hour persisted after the intervention. The results suggest a critical need for bolder interventions to slow traffic and effectively reduce speeding around schools. Recommendations for future policy include implementing a comprehensive package combining:

i. **Reduced Posted Speed Limits:** Lowering limits at all roadways around schools to 30 km/hour. Reducing speed limits to 30 km/hour has previously been associated with a 28% reduction in collision rates in Toronto.

ii. **Automated Speed Enforcement (ASE):** ASE has been found to substantially reduce speeding, violations, collisions, injuries, and deaths around schools.

iii. **Physical Interventions/Traffic Calming:** Implementing physical changes, such as speed humps, curb radii reductions, and flexible in-road traffic signs. The study noted that more than half of the schools lacked any traffic calming measures at their frontages.

Implementing such measures would translate to safer environments for children walking to school, potentially resulting in fewer collisions and the added benefit of increased AST.

2.3.2 Desk Example-2: Surakarta, Indonesia.

A] Introduction



Figure 13. Crash locations in Manahan flyover area. (Youth Participation in School Safety Zones Assessment: A Case Study in Indonesia,2023)

The primary issue was that infrastructure development in Indonesia often prioritizes motorized vehicles, neglecting safer facilities for non-motorized users, leading to increased road safety risks. Specifically, the Y-shaped flyover design and the associated traffic management changes increased driver speeding behaviour. Although

no crashes occurred directly in front of Junior High School 1, the school is located beside the north leg of the flyover, and students reported experiencing near-misses when crossing the street. The flyover design placed its starting point directly in front of the school gate and failed to provide safe pedestrian facilities, such as sidewalks or dedicated crossings (Ellizar et al., 2023)

B] Methodology

The research employed a mixed-methods approach utilizing the International Road Assessment Programme's (iRAP) Star Rating for Schools (SR4S) tool combined with youth participation (Ellizar et al., 2023).

i. **The iRAP Star Rating for Schools (SR4S) Tool**: SR4S is an evidence-based tool to measure, manage, and communicate the risks children face travelling to and from schools. The tool objectively measures the road design star rating for pedestrians (1-star least safe to 5-star safest), and simulates the effectiveness of a selection of road treatment countermeasures. The coding process for SR4S utilises data inputs across ten categories of road attributes, including:
    a. Road Environment (e.g., land use, vehicle parking, sight distance).
    b. Speed (e.g., speed limit, operating speed, speed management).
    c. Sidewalks (presence, road edge, fencing).
    d. Pedestrian Crossing (feature, quality, crossing on main and side road).
    e. Road Features (lines and signs, street lighting).

ii. **Youth Participation Approach:** A participatory design approach involving 30 students from Junior High School 1, divided into five groups and guided by five facilitators from Transport Logi, was used to ensure the proposed solutions met student's needs.

    The participatory process included:

    a. Capacity Building: As shown in figure14, students were equipped with basic knowledge of road safety issues and educated on the standard infrastructure attributes to be considered in the SR4S assessment.

b. Technical Survey: Students conducted field surveys with teachers, undertaking traffic counts and mapping walking route road problems for safety, to experience the traffic context firsthand.



Figure 14. Capacity building on road safety. (Youth Participation in School Safety Zones Assessment: A Case Study in Indonesia,2023)

c. Problem Identification: The main identified problems identified by the students were the absence of safe infrastructure, obstacles for pedestrians in the street, lack of safety awareness, unsuitable design and management of infrastructure, and missing services like no public transport service or monitoring.
d. Design Proposal: Students discussed and developed possible solutions, which were then listed, mapped, and ranked, providing input for the quantitative SR4S assessment.

C] Advocacy and Implementation Limitations

The integration of youth-identified issues with objective SR4S data created a strong foundation for advocacy efforts directed toward the Government of Surakarta City, emphasizing the urgent need for safety improvements around schools. Constructive discussions were held with government representatives to encourage the implementation of the proposed interventions. As an outcome of these engagements, the government acknowledged the importance of enhancing road safety, however, due to budgetary constraints in 2021, only partial measures were executed specifically, the installation of road markings and two pedestrian crossings as shown in figure 15. This limited

implementation highlighted a key constraint of the study, as the final star ratings and projected safety improvements were based on the assumption of full execution of all recommended countermeasures. Consequently, financial and political limitations restricted the realization of the full safety potential envisioned in the proposed plan (Ellizar et al., 2023).



Figure 15. Road markings and pedestrian crossings installed by the Government of Surakarta. (Youth Participation in School Safety Zones Assessment: A Case Study in Indonesia,2023)

D] Proposed Interventions:

The study proposed a set of comprehensive interventions designed to address user needs and enhance pedestrian safety around the assessed school zones. The recommended measures included improving road signage and markings, establishing well-defined pedestrian crossings, reducing the posted speed limit to 30 km/h, enforcing speed regulations, and implementing effective speed management strategies (as shown in figure 16). Simulation results revealed that if all these proposed interventions were fully executed, all seven high-risk locations (as shown in figure 17) would achieve a 4-star or 5-star safety rating, signifying a substantial improvement from the baseline conditions. Moreover, the complete implementation package was projected to reduce pedestrian risk by over 90% across all assessed sites. Among the proposed measures, speed reduction emerged as the most influential factor in elevating overall safety levels,

underscoring the critical role of controlling vehicle speed in protecting vulnerable road users, particularly children (Ellizar et al., 2023).



Figure 16. Manahan flyover area after intervention of star rating. (Youth Participation in School Safety Zones Assessment: A Case Study in Indonesia,2023)

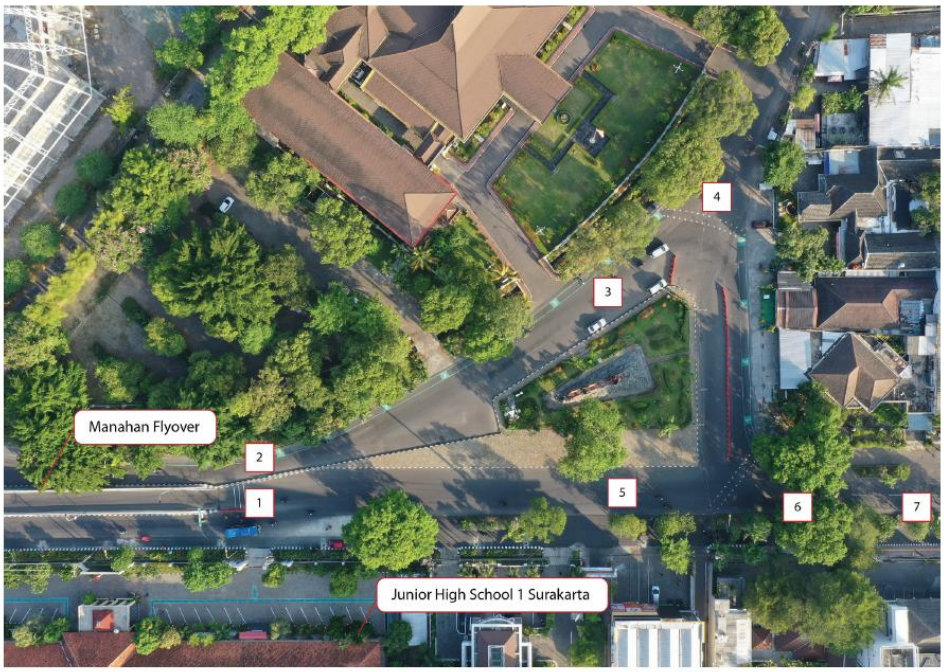


Figure 17. High-risk locations in Manahan flyover area. (Youth Participation in School Safety Zones Assessment: A Case Study in Indonesia,2023)

E] Key Findings

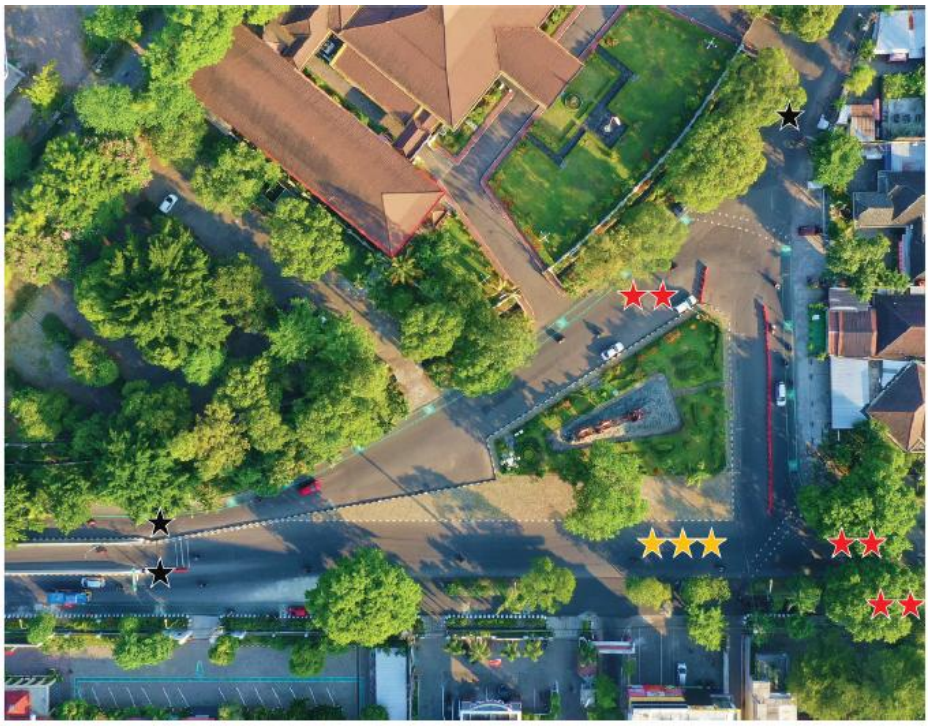


Figure 18. Manahan flyover area before intervention of star rating. (Youth Participation in School Safety Zones Assessment: A Case Study in Indonesia,2023)

The assessment concentrated on seven high-risk locations surrounding the school that were directly affected by the Manahan flyover development. The baseline safety evaluation, conducted using the quantitative Star Rating for Schools (SR4S) analysis, reinforced the concerns raised qualitatively by students, confirming a high level of pedestrian risk. As shown in figure 18, prior to the implementation of any interventions, six of the seven identified locations were rated either 1-star or 2-star, indicating the least safe conditions for pedestrians. Only one location achieved a 3-star rating, highlighting the overall inadequacy of pedestrian safety in the area. These baseline ratings fell short of the Global Road Safety Performance Targets, which recommend a minimum 3-star standard to ensure safe access for children around schools (Ellizar et al., 2023).

F] Conclusions

The case study demonstrates that getting youth involved in recognizing hazards and developing potential solutions using the SR4S tool is a valuable method for road safety planning related to schools. Involving youth is important in that the solutions developed can better respond to their needs and experiences, and further allow for greater

sense of ownership to build among students and community stakeholders. The study effectively combines quantitative estimates (SR4S scores) with qualitative student perspectives (participatory design) in engaging decision-makers about safety risks and required improvements. The study's findings reinforce the critical need for providing safe infrastructure rather than merely focusing on changing child behaviour, given that road traffic crashes remain the leading cause of death globally for young people. The limited implementation of the proposed countermeasures highlights the ongoing challenge of translating advocacy into fully funded and implemented safety improvements. Future studies are suggested to assess the impact after the full range of necessary interventions are implemented by the government.

2.3.3. Desk Example-3: Mumbai, India.

A] Introduction

The safer school zone initiative was implemented in the Byculla neighbourhood in Mumbai, India. This pilot project was a collaboration between WRI India (under the Bloomberg Initiative for Global Road Safety), the Municipal Corporation of Greater Mumbai, the Mumbai Traffic Police, and the Christ Church School.

B] Methodology

The design process for the Christ Church School Zone project was developed in close collaboration with school students to address their needs, aspirations, and preferences for a safer and more engaging experience when accessing their schools. By actively involving children in the design phase, the project aimed to empower them as change makers, fostering a sense of ownership and awareness about road safety and urban design. The implementation adopted a tactical urbanism approach during a trial period, focusing on low-cost, temporary interventions to test and refine the proposed design solutions. The designated school zone extended from the school entrance to the nearest public transport stop, ensuring that students traveling from longer distances could be conveniently dropped off at the edge of the zone and complete the remainder of their journey on foot. For this pilot initiative, the school zone covered an approximate 200-meter stretch that served both Christ Church School and St. Agnes School. To evaluate the effectiveness and impact of the transformation, a structured survey was conducted before and during the trial period involving 120 participants which comprises 40

children, 40 pedestrians, 20 business operators, and 20 motorists that provided valuable insights from multiple stakeholders directly interacting with the school zone environment.

C] Interventions

The project implemented six specific design elements aimed at improving the areas surrounding the school for children:

i. **Delineation of School Zones:** As shown in figure 19, this ensures students feel confident walking to school. The boundaries allow parents to drop off children at the edge, encouraging them to walk the final stretch. It also alert drivers that they are entering in the school zone.



Figure 19. Delineation of School Zones. (WRI, 2021)

ii. **Road Markings and Signage:** As shown in figure 20, Road markings and signage provided a means of establishing an orderly flow of traffic.



Figure 20. Road Markings and Signage. (WRI, 2021)

Signs included ‘School Zone’ and ‘School Zone Ahead’ marking the start of the school zone. Other signs utilized included pedestrian crossing signage, 'Slow Down' and 'Stop' signage in particular at crossing points and intersections.

iii. **Vibrant Pedestrian Crossings:** As shown in figure 21, these crossings combined traditional zebra markings along with some colour markings to increase visibility for all street users to become more aware of each other. In this trial, the crossing was painted just outside the front entrance of the Christ Church School with bright colours to alert motorists to stop and yield to pedestrians.



Figure 21. Vibrant Pedestrian Crossings. (WRI, 2021)

iv. **Bulb-outs:** As shown in figure 22, these are extensions to footpaths that serve a dual purpose-they reduce the crossing distance for pedestrians and limit their exposure to moving vehicles. Bulb-outs were placed at locations where children typically waited before crossing and were found to help reduce speeds by 2-8 kph.

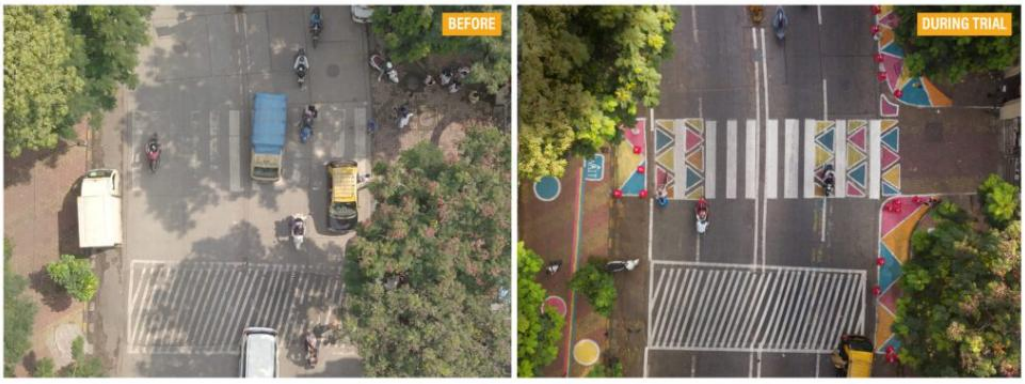


Figure 22. Bulb-out. (WRI, 2021)

v. **Speed Calming Measures:** As shown in figure 23, these measures are crucial where pedestrians frequently approach moving vehicles, especially at intersections lacking signals and crossings. As vehicle speed increases, the driver's field of vision narrows, making it harder to see small children or react to sudden events, given that children have a limited understanding of speed and developing cognitive skills. Speed calming measures near Christ Church School and St. Agnes School entrance helped regulate speeds at crossings by 17%.



Figure 23. Speed calming Measures. (WRI, 2021)

vi. **Informative Footpaths:** As shown in figure 24, the design included vibrant coloured pavement markings, basic road markings and walk zone guide strips to enrich the walking along the footpath from a child's perspective.



Figure 24. Active, Vibrant, and Informative Footpath. (WRI, 2021)

The markings directed children to the school entrance and other public spaces. The guide strips established a clear walking zone framed with bright coloured signs that said ‘Wait’ to encourage children to move towards safety.

D] Key Findings

The assessment conducted before and during the trial demonstrated significant improvements in safety perception and motorist compliance within the school zone. The survey findings indicated that 41.3% of motorists stopped at the newly implemented vibrant pedestrian crossing, marking a substantial increase from only 9.8% of motorists who stopped at a nearby crossing without such interventions. Furthermore, the perception of safety among users showed a remarkable enhancement, with 98% of respondents reporting that the street felt safer during the trial period compared to the pre-trial conditions. Accessibility also improved notably, as 93% of children surveyed expressed that the street had become more accessible and easier to navigate. Additionally, the introduction of bulb-outs and other speed-calming measures contributed to a measurable reduction in vehicle speeds and bulb-outs alone reduced speeds by 2–8 km/h, while the overall interventions regulated crossing speeds by approximately 17%. These outcomes collectively highlight the effectiveness of the implemented safety measures in creating a more secure and child-friendly school zone environment.

E] Conclusion

The success of the Christ Church School Zone Trial effectively demonstrated to local authorities how small-scale, tactical changes in street design can lead to significant improvements in safety for children. The trial served as a powerful demonstration project, enabling the Municipal Corporation of Greater Mumbai to build a strong case for permanently transforming the area into a child-friendly school zone. Beyond the local impact, the positive outcomes of the project initiated broader discussions within the state of Maharashtra about the importance of scaling up such interventions and implementing safer school zones across various cities. The key learning from this initiative highlights that the resulting State-wide Safe Access to Schools Initiative holds immense potential to promote active modes of transportation among children, such as walking and cycling. Encouraging these habits not only fosters a healthier and more active lifestyle among

students but also contributes to the reduction of carbon emissions, aligning with broader goals of sustainability and urban liveability.

2.3.4. Desk Example-4: Gurugram, India.

A] Introduction

The "Road Safety & Juniors: Paving the Way for a Safer Tomorrow" project, led by the Road Safety NGO TRAX, aims to develop a safer culture around schools in India. TRAX has been actively advocating for Safe School Zones in India since 2017. The initiative targets high-risk locations around selected schools in Gurugram, Faridabad, and New Delhi.

The central goal of this initiative is to ensure that children have at least 3-Star or better journeys to school using SR4S. The project involves road upgrades, research, and training, engaging students, teachers, and the wider community. Key partners supporting this project include the Government of Haryana and MG Motor (Gurugram & Faridabad, 2017).

B] Methodology

TRAX utilizes the SR4S (Star Rating for Schools) tool to carry out two important assessments: one, to assess the school zone's baseline risk levels, and two, to assess the risk after improvements have been made with respect to the intervention. These assessments are key in shaping the design and delivery of targeted infrastructure upgrades and educational programs that would prevent fatalities and injuries amongst school children. The assessments provide evidence to objectively prioritize safety improvements and track the effect of modifications on safety. TRAX has utilized this approach to inform and develop Safe School Zones at three schools, demonstrating the tool can be used to convert safety assessments into meaningful, lifesaving activities (Gurugram & Faridabad, 2017).

C] Interventions

Interventions were undertaken in consultation with local authorities and with specific direction from IndiaRAP. These actions centered on resolving identified issues with road infrastructure:

i. Gurugram (Government Boys Senior Secondary School)



Figure 25. Government Boys Secondary School Gurugram, before interventions (Road safety & juniors paving the way for a safer tomorrow, 2020)



Figure 26. Government Boys Secondary School Gurugram, after interventions (Road safety & juniors paving the way for a safer tomorrow, 2020)

As a result of the assessment, which indicated serious issues with sidewalk encroachment by vendors (as shown in figure 25), TRAX engaged undertook a set of targeted infrastructure improvements to support safety and accessibility in

school zones. As shown in figure 26, these interventions included improved signage for speed limits and clearer warnings for motorists, adding pedestrian fencing to direct children to cross safely and minimize unsafe entry into the roadway, and upgraded sidewalks that gave students unobstructed pathways to safely get to and from school. Taken together, these interventions addressed identified challenges locally and meaningfully contribute to overall safer and more orderly school zones.

ii. Faridabad (Government High School Sahupura, Sector 65)

The improvements at this location addressed student safety and vehicle speed within the school zone. As shown in figure 27, the main strategies involved the addition of a clearly marked pedestrian crossing to improve student movement, installing speed humps to calm traffic and discourage speeding, and enhancing the character of the road to improve visibility and lane assignment. In addition, school zone warning signs to alert drivers of children and encourage careful driving behaviours were added. Altogether, these actions lead to a safer and more organized zone for students arriving to and departing from school.



Figure 27. Government High School Sahupura Faridabad, before and after interventions (Road safety & juniors paving the way for a safer tomorrow, 2020)

iii. Faridabad (Government Model Senior Secondary School, Sector 28)

Before implementing infrastructure improvements on Link Road, advocates made every effort to highlight the immediate need to make the area safer for students at school. As a result of this effort, several significant changes were made to improve safety, including installing a zebra crossing for safer pedestrian crossings, adding rumble strips and crosswalks (as shown in figure 29) to slow vehicles, and creating a paved shoulder for a safer space for students to walk. They also added speed limit signs and school warning signs (as shown in figure 28) for driver awareness and speed reduction, as well as other traffic calming measures to minimize the speed of vehicles and increase safety for schoolchildren at the school and others who share the road.



Figure 28. Government Model Senior Secondary School Faridabad, after interventions (Road safety & juniors paving the way for a safer tomorrow, 2020)



Figure 29. Government Model Senior Secondary School Faridabad, after interventions (Road safety & juniors paving the way for a safer tomorrow, 2020

D] Key Findings

The most significant measurable outcome was the consistent improvement of safety ratings, with all reviewed schools transitioning from 2-Stars to 3-Stars, thereby meeting the minimum safety benchmark for “Safe School Zones” Specifically, the Government Boys Senior Secondary School in Gurugram, the Government High School in Sahupura, Faridabad, and the Government Model Senior Secondary School in Faridabad each recorded measurable safety upgrades following the implementation of interventions.

These projects collectively achieved their 3-Star safety targets, demonstrating the success of data-driven, locally adapted solutions. The infrastructure improvements prioritized essential safety measures such as enhanced signage like speed limits and warning signs, the installation of traffic calming devices such as speed humps and rumble strips, and the upgrading of pedestrian infrastructure through marked crossings, fencing, and widened or improved sidewalks. Moreover, the participatory design process facilitated the identification and resolution of context-specific issues such as the encroachment of sidewalks by vendors in Gurugram which is ensuring that interventions were not only technically sound but also socially responsive. Overall, these findings highlight that structured, evidence-based planning combined with community engagement can substantially improve road safety outcomes in school environments (Gurugram & Faridabad, 2017).

E] Conclusion

The TRAX India Road Safety & Juniors Project, utilizing the SR4S tool, provides a clear model for enhancing road safety infrastructure around vulnerable school zones. By systematically measuring risk and implementing evidence-based upgrades such as traffic calming and improved pedestrian crossings, the project has successfully transitioned assessed school zones in Gurugram and Faridabad from 2-Star risk levels to the minimum acceptable 3-Star safety rating. This success ensures a safer environment and commute for students, paving the way for further safety improvements in other high-risk areas across India.

2.4. Conclusion of Literature Review

School zones represent one of the most vulnerable spaces in urban transport systems, where a high concentration of children interacts with mixed traffic under inconsistent infrastructural, behavioural, and enforcement conditions. This study examined global and Indian perspectives on child pedestrian safety, analysed policy frameworks, identified key infrastructural and behavioural parameters, and evaluated best practices through international and national desk examples. The findings establish that despite the presence of IRC guidelines (IRC:103-2012; IRC:SP:32-2023), the absence of a unified, enforceable, child-centric safety policy results in fragmented implementation, missing pedestrian infrastructure, poor speed control, and limited community participation.

Literature and case examples from Toronto, Surakarta, Mumbai and Gurugram demonstrate that school zone safety significantly improves when interventions integrate traffic calming, continuous walkability, clear signage, surveillance, and stakeholder engagement. Advanced assessment tools such as GIS mapping, walkability audits, simulation modelling (SFM), and Surrogate Safety Measures further reinforce the need for evidence-based planning.

The study concludes that improving school zone safety in India requires a multi-dimensional framework combining engineering solutions, behavioural change, enforcement, and participatory planning. A children-inclusive approach grounded in global best practices and strengthened by local context can substantially reduce risks and transform school environments into safe, accessible, and equitable zones for all students.

2.5. Key Takeaways

i. **Infrastructure is the strongest determinant of safety.**
   Evidence from global and Indian studies consistently shows that the presence of wide sidewalks (minimum 1.8 m), raised crossings, traffic calming features, and controlled intersections directly reduces pedestrian-vehicle conflicts and vehicle speeds.

ii. **Behavioural factors intensify risk, especially during peak school hours.**

Common driver behaviours such as speeding, distraction, and impatience remain significant contributors to risk. For children, impulsivity and group movement, especially in afternoon hours, increase exposure to unsafe crossings.

iii. **Advanced assessment tools strengthen decision-making.**
GIS hotspot analysis, walkability indices, microscopic simulations, and SSMs provide accurate insights to prioritize locations, test interventions, and predict risk even in the absence of adequate crash data.

iv. **International practices highlight integrated and multidisciplinary solutions.**
Safe Routes to School (SRTS), Vision Zero, and community-driven projects demonstrate that combining engineering with enforcement, education, and engagement creates sustainable improvements.

v. **Community and stakeholder involvement is essential.**
Parents, students, school staff, traffic police, municipal agencies, and local residents play crucial roles in ensuring that interventions are practical, accepted, and maintained.

2.6. Tools and Analysis Study

A comprehensive set of analytical, spatial, behavioural, and evaluative tools was examined in this study. These tools form the backbone of evidence-based school zone planning and directly influence how risks are identified, how interventions are prioritised, and how safety performance is measured before and after design changes. The tools extracted from global best practices, national guidelines, and academic research played a crucial role in shaping the methodological and analytical approach of this study.

i. GIS-Based Spatial Analysis Tools

Geographic Information Systems (GIS) is widely used as an analytical and decision-support tool in school zone safety planning, enabling the integration, mapping, and visualisation of multiple spatial datasets. It helps planners examine the spatial distribution of schools, analyse road networks, identify hazardous locations, and assess how various environmental factors influence child pedestrian safety. GIS supports hotspot identification by overlaying crash data with land use, traffic patterns, and pedestrian infrastructure, allowing prioritisation of zones that require immediate

intervention. It is also used to generate buffer zones around schools, evaluate walkability, study accessibility patterns, and model safe routes for students.

ii. Walkability and Pedestrian Environment Assessment Tools

Walkability assessment tools, such as the School Walkability Index (SWI), walkability checklists, and on-site pedestrian environment assessment are widely used to evaluate the quality, safety, and comfort of pedestrian infrastructure around school zones. These methods systematically examine key parameters including footpath continuity, width, surface quality, and the presence of obstructions such as encroachments, parked vehicles, or vendors. They also assess the safety of crossings by reviewing zebra markings, signals, guardrails, and refuge islands, along with evaluating visibility, lighting conditions, traffic exposure, and prevailing vehicle speeds. By capturing both physical conditions and experiential factors, walkability tools provide a holistic understanding of pedestrian safety and accessibility. They help identify infrastructure gaps, compare existing environments against global benchmarks, and incorporate the perceptions of children and caregivers, thereby bridging the gap between technical design standards and actual user comfort.

iii. Behavioural Observation and Video Analytics Tools

Understanding behavioural risk is essential in school zones, and a range of analytical tools is used globally to capture and quantify these risks. Structured behavioural observation templates help document recurring patterns in driver and pedestrian behaviour, while CCTV-based deep-learning video analytics offer automated insights by detecting and classifying movements in real time. Advanced computer-vision techniques such as trajectory extraction through algorithms like YOLO and SORT further enable the tracking of pedestrian and vehicle paths with high precision. Together, these tools allow the identification of subtle but high-risk behaviours, including drivers failing to yield at crossings, sudden pedestrian dash-outs, children crossing in groups or between parked vehicles, variability in speeding behaviour between mid-block sections and intersections, and distracted driving involving mobile phone usage or aggressive manoeuvres. The increasing use of these technologies worldwide highlights their effectiveness in quantifying risky

interactions and generating evidence that supports targeted, context-specific safety interventions.

iv. Surrogate Safety Measures (SSMs)

Surrogate Safety Measures (SSMs) are proactive analytical tools used to evaluate traffic safety in situations where crash data is insufficient, unreliable, or unavailable, these conditions commonly observed in many Indian urban contexts. Instead of relying on historical accidents, SSMs estimate the likelihood and severity of potential conflicts by analysing how close road users come to dangerous interactions. Key measures include Time to Collision (TTC), which evaluates how soon two road users would collide if their paths remain unchanged, Post Encroachment Time (PET), which measures the time gap between one road user leaving a conflict point and another entering it, Pedestrian Safety Margin (PSM), which assesses pedestrian exposure and the buffer available during crossing and Predicted Collision Risk (PCR), which uses deep-learning-based trajectory prediction to forecast near-miss events. These metrics allow detailed assessment of risk at micro-locations such as crosswalks, school gates, and intersections. Importantly, they also help evaluate the safety impact of proposed design interventions even before physical implementation, making SSMs essential for evidence-based school zone safety planning.

v. Simulation and Modelling Tools (Social Force Model, Microscopic Simulation)

Simulation is a vital tool for assessing the impact of infrastructure interventions without requiring physical implementation, making it especially valuable in school zone safety planning. Models such as the Social Force Model (SFM) and microscopic simulation platforms like PTV Vissim or Viswalk allow researchers to predict pedestrian movement patterns, quantify pedestrian-vehicle conflicts, and test the effects of geometric modifications such as sidewalk widening, speed hump placement, or crossing redesigns. These tools also support pre-implementation evaluation of expected speed reduction and behavioural changes, enabling planners to compare multiple design alternatives efficiently. Evidence from the literature demonstrates the strength of simulation-based analysis like SFM modelling, for example, recorded a 44.4% reduction in pedestrian-vehicle conflicts when sidewalk

width was increased from 2.5 m to 3.5 m. Such quantifiable outcomes highlight the powerful role of simulation in designing safer, more child-friendly school environments and in supporting data-driven decision-making.

vi. School Star Rating Tools (SR4S)

The Star Rating for Schools (SR4S) tool developed by iRAP is a globally recognised, evidence-based method used to evaluate and benchmark safety conditions around schools. It assigns a safety rating ranging from 1-star, indicating the least safe environment, to 5-stars, indicating the highest level of safety. The rating is determined by assessing key factors such as road width and crossing distance, the presence and quality of footpaths, prevailing traffic speeds, pedestrian volumes, the degree of separation between pedestrians and vehicles, and the visibility and clarity of signage. SR4S has been widely adopted in countries such as Indonesia, the Philippines, and Malaysia to advocate for safer school zone designs and prioritise infrastructure upgrades. Its strength lies in its simplicity, strong empirical foundation, and ability to communicate complex safety risks in a clear manner that supports informed decision-making by policymakers and urban planners.

vii. Speed Monitoring and Enforcement Tools

A variety of technological tools are used globally to support speed management and enforcement in school zones, forming a critical component of overall safety strategies. These include speed radar guns for on-site monitoring, automated speed cameras that detect and record violations without manual intervention, LED speed feedback signs that alert drivers to their current speed, and flashing beacons or dynamic warning systems that provide high-visibility alerts during school hours. Together, these tools play a central role in reducing speeding behaviour and enhancing driver compliance with designated speed limits. Evidence from international studies shows that automated enforcement measures alone can reduce speeding violations by up to 50%, particularly in environments where behavioural change is difficult to achieve through advisory signage or road markings. Their effectiveness underscores the importance of integrating technology-driven enforcement into school zone safety planning to create more predictable and controlled traffic environments.

viii. Stakeholder Feedback and Perception Tools

To capture the experiential and perceptual dimensions of safety around school zones, the study employed a range of qualitative tools, including parent and student perception surveys, interviews with teachers and school administrators, stakeholder mapping techniques, and focus group discussions. These methods together provided deeper insights into the lived experiences of users, helping to uncover hidden behavioural risks, subjective concerns, and localised issues that are often overlooked in purely technical assessments.

2.7 Way Forward

In the next semester, the study will progress from the literature and policy review stage to detailed on-ground assessment and analysis. Field surveys will be conducted to document pedestrian movement, vehicular speeds, traffic volumes, and the condition of existing infrastructure such as footpaths, crossings, signage, and pick-up/drop-off areas etc. Student travel behaviour and safety perceptions will also be recorded through observations and brief questionnaires. Based on the parameters developed through the literature review, the study area will be systematically assessed to identify infrastructural deficiencies, behavioural risks, and gaps in compliance with IRC guidelines. The spatial and primary data will be analysed to determine key safety concerns such as missing crossings, lack of signage, unsafe sidewalks, and high-conflict points. Using these findings and insights from global desk examples, a set of children-inclusive planning and safety interventions will be developed for the study area. These proposed interventions will subsequently be validated through stakeholder inputs and technical review, followed by submission to the concerned authorities for feedback and approval, ensuring that the proposed solutions are aligned with regulatory frameworks. During the upcoming phase, the chapters on site analysis, existing situation assessment, proposed interventions, and consolidated recommendations will be completed, along with the preparation of the required maps, figures, and visual documentation. This phase will strengthen the practical applicability of the study and pave the way for evidence-based implementation.

CHAPTER 3

RESEARCH DESIGN

3.1. Aim

To improve school zone safety by identifying risks, evaluating current interventions, and suggesting improvement for safe travel of children.

3.2. Objective

3.2.1. Phase-1

1. To understand the concept of school zones in the perspective of urban planning, safety, policies and guidelines.
2. To study global and national literature on child pedestrian safety and school zone design.
3. To determine the parameters based on the existing practices implemented for safe school zone.
4. To compare the Provisions of the Indian Policies and the guidelines with the Global reference.

3.2.2. Phase-2

5. To identify study area based on schools where students of various Socio-Economic background study.
6. To delineate the School Zone which need immediate attention.
7. To analyse requirement and need of various student group in School Zone.
8. To Propose Children Inclusive Planning and Safety Interventions for School Zones.

3.3. Scope

The study focuses on understanding and enhancing school zone safety through student centric planning and pedestrian inclusive strategies. It addresses the recognition of major hazard and concerns about children, for example, traffic hazards, unsafe pedestrian facilities, and poor enforcement of safety rules. The research examines current policies and planning approaches, study gaps, and takes into account best practices elsewhere to offer targeted insights on the safety of school zones. The scope involves primary data

collection via surveys eliciting children's opinions and secondary data from related sources to provide a holistic analysis. The results seek to emphasize strategies and interventions in developing safer and inclusive school settings.

3.4. Limitations

1. The study will be restricted to selected urban areas and certain school zones, which may limit the generalizability of outcomes to other urban cities.
2. This study will not include an economic or cost-benefit analysis of school zone safety interventions. It will not evaluate the financial feasibility, budgetary implications, or economic efficiency of the proposed measures.

CHAPTER 4

SITE SELECTION

A well-justified site selection is integral to any urban research that takes a spatial approach, particularly when the aim is to enhance safety for vulnerable road users such as school aged children. In rapidly urbanizing Indian cities, school zones are particularly complicated places, where pedestrians interact with motorized and sometimes non-motorized traffic, on-street commercial activities, and institutional land uses. To understand how all these elements interact and even create multiple types of safety vulnerabilities, site selection becomes especially important. This is because we have to select a site where all these interconnections can be observed, framed, measured, and importantly, are relevant to the urban reality.

For the purposes of this dissertation, the school zone of Shivaji Nagar (in Bhopal, Madhya Pradesh) was selected to serve as the study area. The Shivaji Nagar locality has a dense concentration of schools along busy urban circulation corridors, which experience repeated and recurring traffic conflicts. Before the specifications of the selected Shivaji Nagar, it is important to situate the concern within a larger context and smaller context of road safety, as this is a stacked and scaled approach to convey the relevance of selecting a site.

4.1. Road Accidents in Madhya Pradesh

Madhya Pradesh is one of the biggest states in India in terms of both area (as shown in figure 30) and population, resulting in a vast network of sometimes poor, sometimes diverse roads connecting rural communities to fast paced, developing urban centres. Over the last 10 years, it has always been considered one of the top contributors to the road accident numbers in India (*ROAD ACCIDENTS IN INDIA 2023*, 2023).

Based on the annual road safety report published by the Ministry of Road Transport and Highways, it was ranked the 2nd highest number of road accident in 2023, with 55,327 accident (*ROAD ACCIDENTS IN INDIA 2023*, 2023). Many structural and behavioural factors contribute, with rapid motorisation, limited improvements to road safety and infrastructure, growing urban sprawl, mixed land use adjacent to fast moving corridors, and limited enforcement to manage speed in particular around schools.

With the rapid development of major cities like Bhopal, Indore and Gwalior, the issues surrounding safe mobility have become even more pronounced. School zones often face challenges such as Crosswalks are either poorly designed or missing, parking is unregulated around schools and near gates, sidewalks are either non-existent, too narrow or discontinuous and there are low or confusing amounts of signage that would assist children/ guardian with navigating school zones on foot. Conducting a community-level assessment is crucial for fully understanding the school zone challenges mentioned.

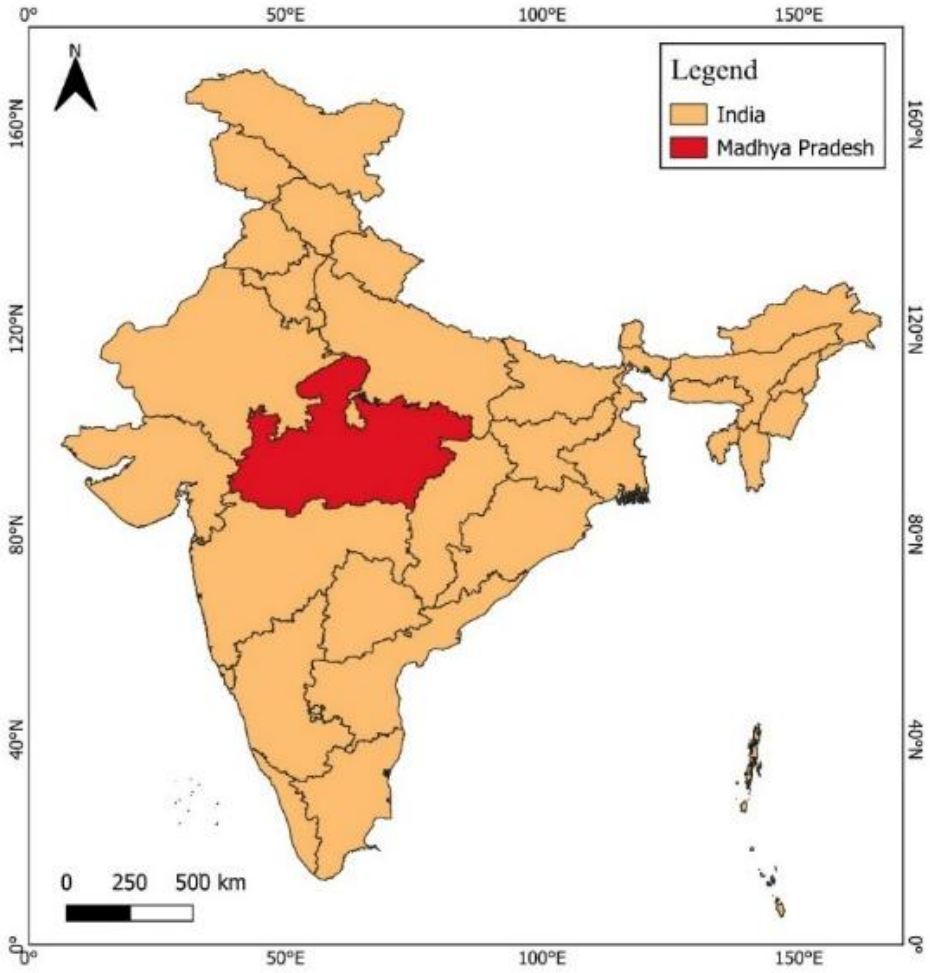


Figure 30. Location of Madhya Pradesh in India (Author)

4.2. Bhopal's Road Safety Profile

Bhopal (as shown in figure 31), the capital city in Madhya Pradesh, is a fast-growing urban area with complicated road hierarchies, increasing ownership of private vehicles, and a dense clustering of institutional land uses. The city makes the list of the top 10 Million Plus cities in India where road accidents have occurred and documented

2,906 road accidents in 2023 (*ROAD ACCIDENTS IN INDIA 2023*, 2023). Two-wheeled riders and pedestrians were the most vulnerable.

Given this condition, Bhopal is a suitable urban environment to examine the design characteristics of school zones and identify safety deficiencies.

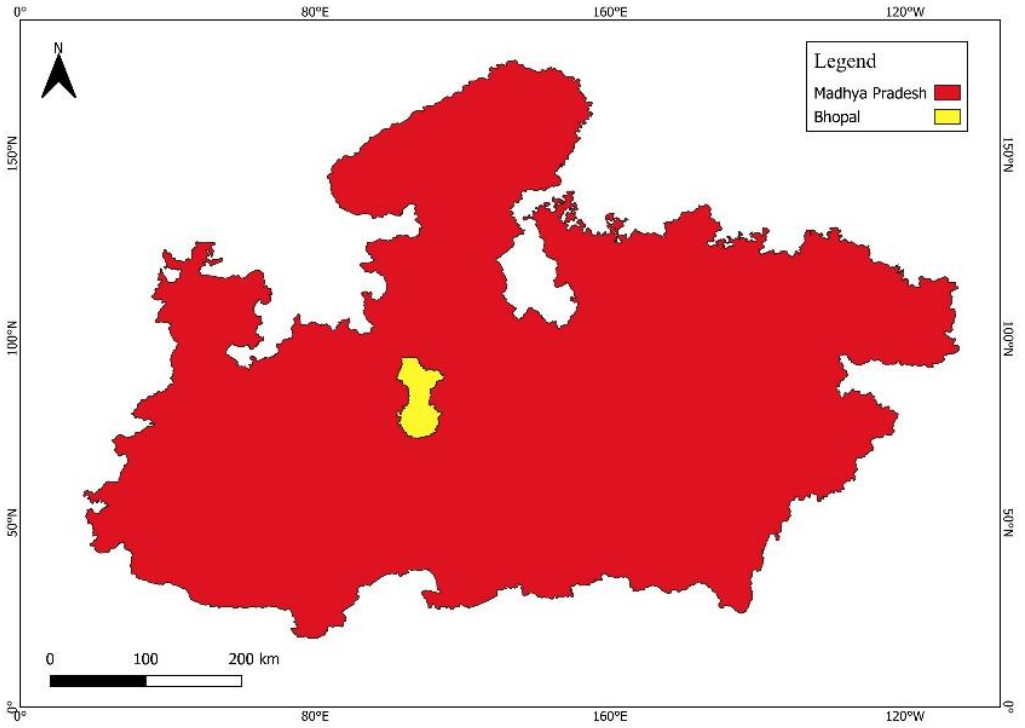


Figure 31. Location of Bhopal in Madhya Pradesh (Author)

4.3. GIS-Based Work Undertaken for Site Identification

To identify an appropriate school zone for further analysis in Bhopal, a structured, GIS-based, method was used. The objective of this work was to understand the spatial patterns of schools, analyse accident patterns within a specific jurisdiction and to select a site that exemplifies common safety issues in school zones in urban India. All GIS Analysis, was completed in QGIS.

4.3.1. Mapping of Schools Across Bhopal

The first step consisted of mapping all of the known schools in Bhopal by using the list of school obtained from the Joint Director Education Office, Bhopal. As illustrated in figure 32, the location of each school was geocoded and plotted in the GIS

environment, which created a rich spatial data-base of educational facilities across the city.

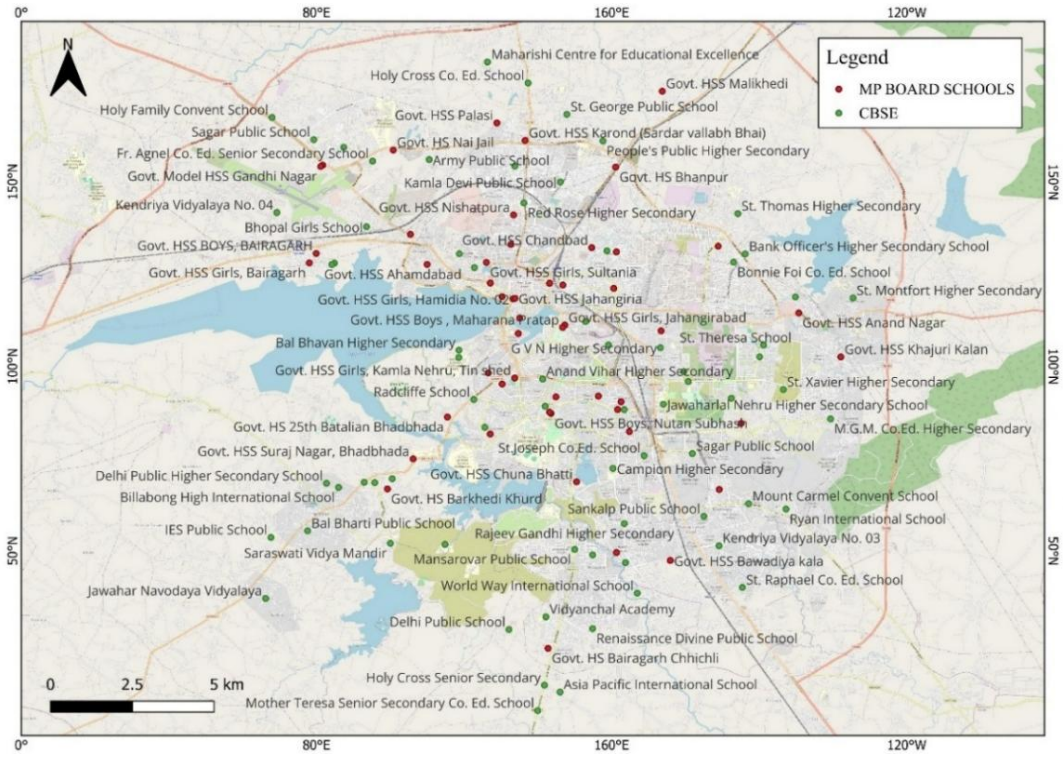


Figure 32. Schools of Bhopal (Author)

This mapping provided an opportunity to characterize clustering of schools across different areas of the city, and to visualize larger scale patterns of child-based pedestrian activity across Bhopal, which was necessary for assessing school-zone safety conditions.

4.3.2. Overlay of Ward Boundaries for Spatial Screening

To establish a systematic framework for identifying suitable study locations, the ward boundaries of Bhopal were overlaid onto the mapped school locations within the GIS environment, as shown in figure 33. The ward map provided an administrative spatial structure through which the distribution and concentration of schools could be comparatively examined across different parts of the city. Using ward boundaries as the analytical unit enabled a more organized and location-specific assessment of educational concentration patterns. This approach also helped in understanding how schools were spatially distributed within different urban contexts and circulation networks across Bhopal.

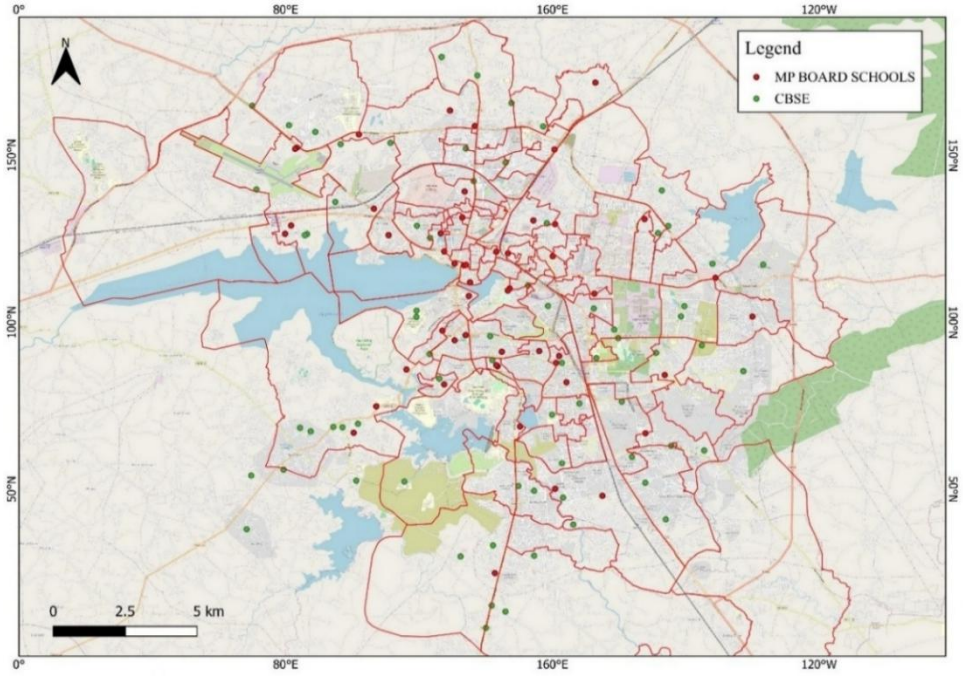


Figure 33. Overlay of Ward Boundaries for Spatial Screening (Author)

4.3.3. Identification of Wards with High School Density

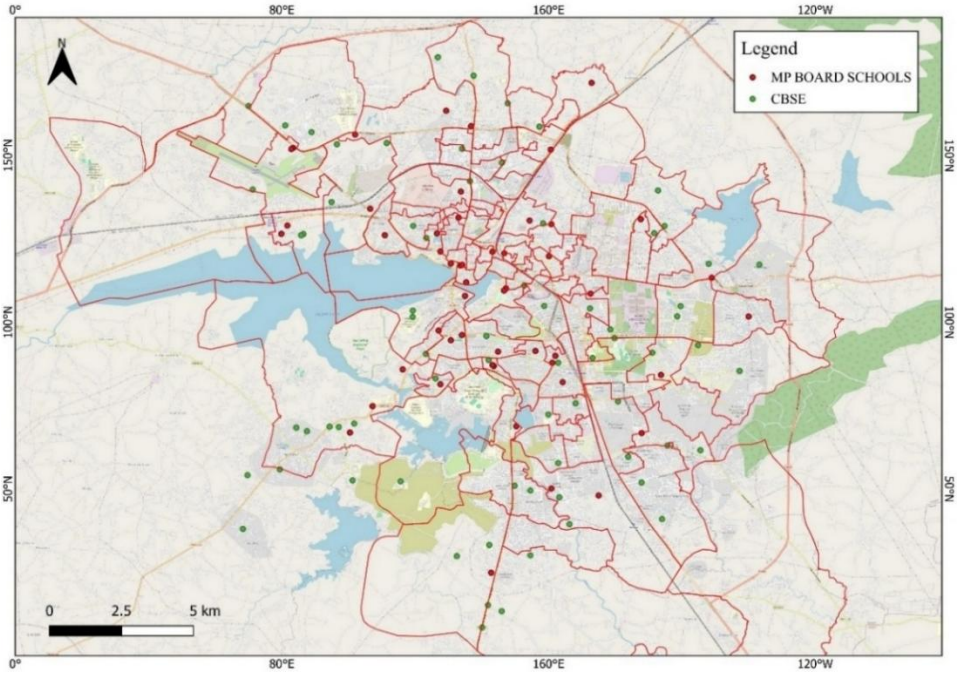


Figure 34. Identification of Wards with High School Density (Author)

After overlaying the mapped school locations on the ward boundary map, certain wards emerged as having a significantly higher concentration of schools compared to

others. Among these, the ward containing Shivaji Nagar exhibited one of the densest clusters of educational institutions within a relatively compact urban area, as shown in figure 34. While schools in several wards were either dispersed or moderately concentrated, the Shivaji Nagar ward demonstrated a strong spatial clustering of schools located in close proximity to one another.

4.3.4. Collection and Mapping of Accident Data for the Study Area

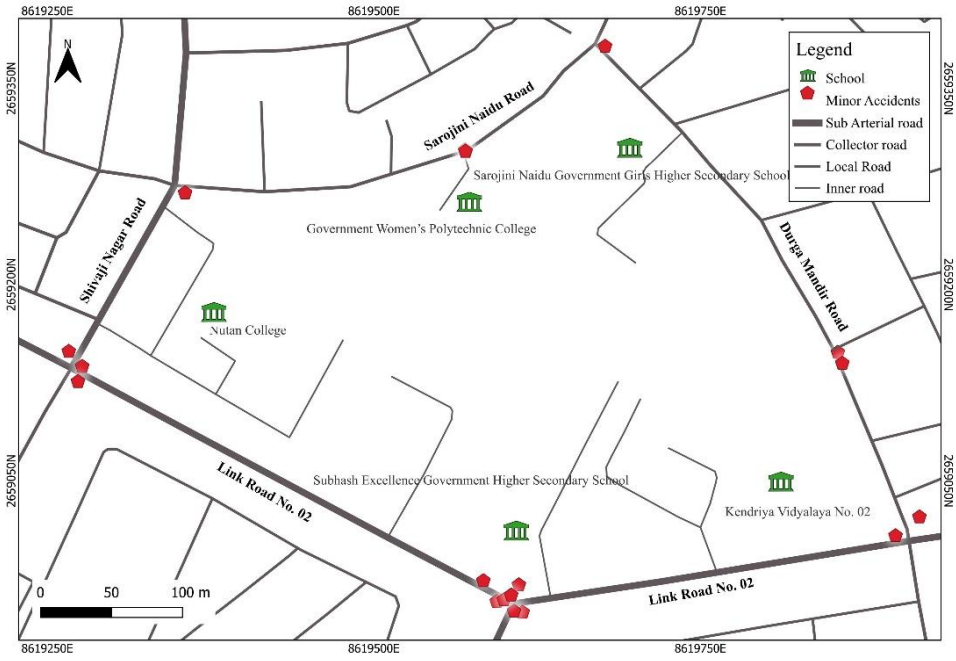


Figure 35. Marking the Minor Accident in School Area (Author)

In contrast to datasets on accidents at a citywide level, the local accident records were obtained directly from Habibganj Police Station, which is the area of jurisdiction for the school zone of Shivaji Nagar and the surrounding road network. As shown in figure 35, the accident data from the police station was also geocoded and plotted on GIS, allowing for analysis in relation to nearby school boundaries. By using mapping as part of our analysis, we were able to identify junctions and stretches of road with known accident history, conflict points near school entrances, and road segments that had higher vulnerabilities for pedestrian safety. Therefore, the accident analysis in this study was both detailed and targeted to the specific context area, providing evidence of accident and issues of safety, accuracy, and relevance rather than large, citywide datasets that are not as context specific.

4.4. Profile of the Selected Site: Shivaji Nagar, Bhopal

Shivaji Nagar is situated in the central administrative zone of the city of Bhopal. It is also in close proximity to important nodes in the vicinity such as the Board Office, Link Road No. 02 and the Rani Kamlapati Railway Station are the features which contribute to the area being one of the busiest public corridors in Bhopal. The location also has a number of government and private schools located closely together making it a school zone like environment.

4.4.1. Educational Institutions in the Vicinity

Shivaji Nagar contains various clusters of significant educational institute that: - Subhash Government Higher Secondary School, Kendriya Vidyalaya No. 02, Sarojini Naidu Government Girls Higher Secondary School, Government Women's Polytechnic College, Sarojini Naidu Government Girl's Post Graduate College (as shown in figure 36).

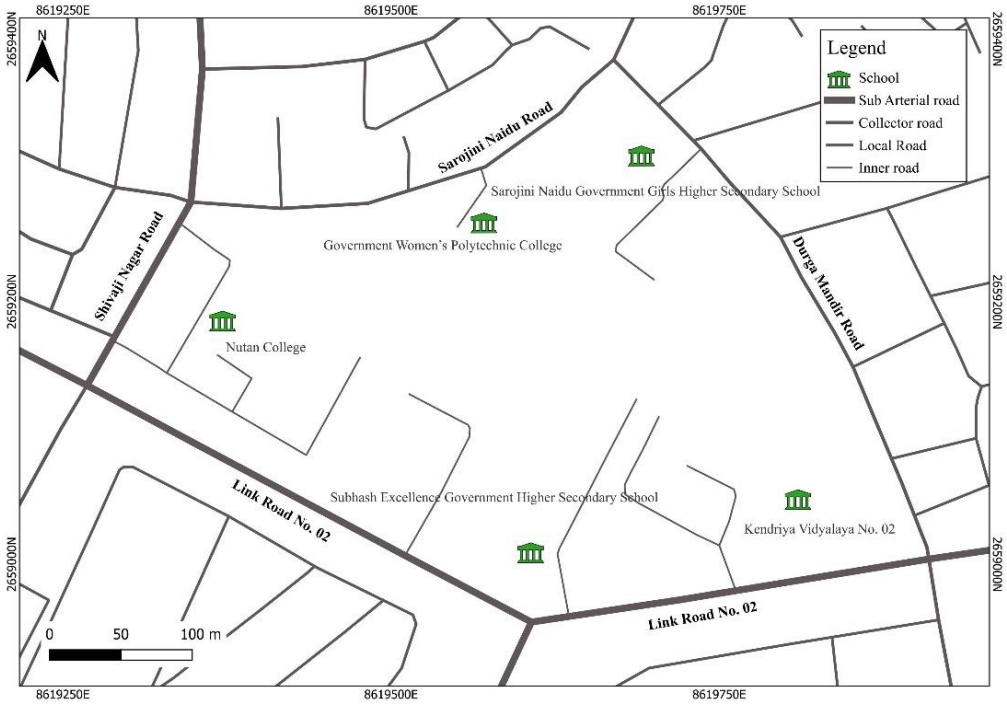


Figure 36. Educational Institutions in the Vicinity (Author)

The high density of educational facilities contributes to overlapping pedestrian flows, shared drop-off locations, opening hours, and closing hours, leading to increased

pressure on local roads and pedestrian infrastructure which further enhances the necessity for a systematic safety evaluation.

4.4.2. Public Transport Accessibility (Bus Stop Distribution)

As shown in figure 37, the study area is well served by public transport, as evidenced by the presence of multiple bus stops distributed along major roads such as Shivaji Nagar Road, Link Road No. 02, and Durga Mandir Road. A notable concentration of bus stops is observed near key educational institutions, particularly around Nutan College, Subhash Government Higher Secondary School, and Kendriya Vidyalaya No. 02, indicating that buses are a primary mode of transport for students and staff. The close spacing of these bus stops suggests overlapping service catchments, which increases the frequency of bus halts along already busy road segments.

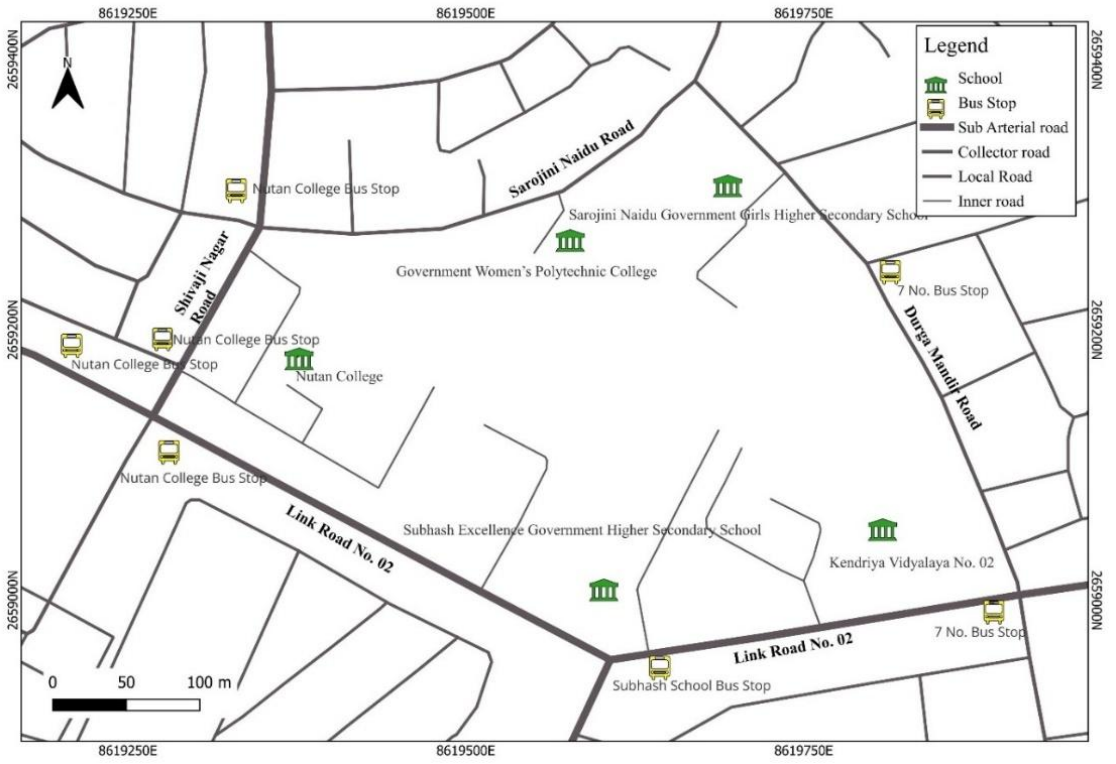


Figure 37. Bus Stops in School Area (Author)

This pattern contributes to localized congestion, especially during peak school hours when buses, private vehicles, and pedestrians converge simultaneously. The absence of designated bus bays and organized pick-up and drop-off zones leads to buses stopping directly on the carriageway, disrupting traffic flow and creating conflict points.

Additionally, students often cross roads informally while accessing bus stops, as there is limited provision of safe pedestrian crossing infrastructure.

4.4.3. Land Use Characteristics

As shown in figure 38, the land use pattern surrounding the institutional cluster consists primarily of public and semi- public, residential, and commercial activities. The presence of residential neighbourhoods near the schools encourages walking and cycling among students who live nearby. At the same time, commercial establishments such as small shops, food vendors, and stationery stores generate additional pedestrian activity around school entrances.

This mixed land use environment contributes to the vibrancy of the area but also increases the complexity of traffic interactions. The overlap between educational travel and local commercial activity results in higher pedestrian volumes and frequent roadside activity, particularly during school opening and closing hours.

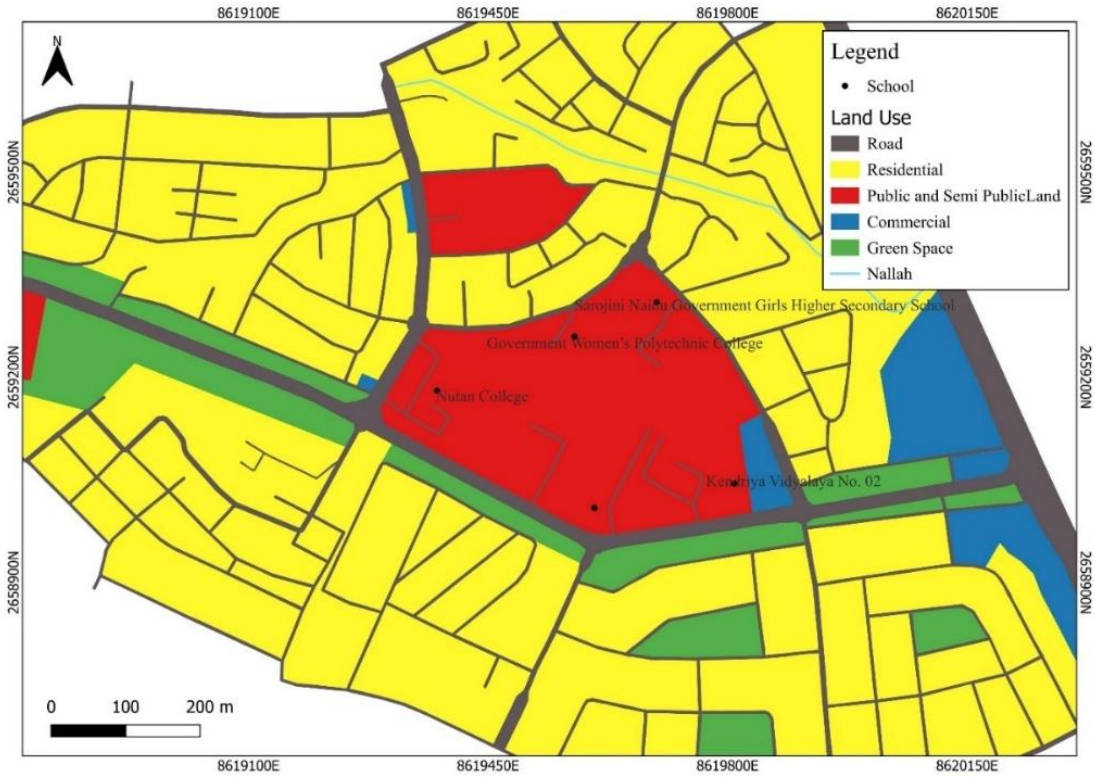


Figure 38. Land Use Map (Author)

4.4.4. Road Network and Traffic Flow

Key roads impacting mobility in Shivaji Nagar include link road no. 1, link road no. 2, Roshanpura square, Polytechnic square, Board Office, Rani Kamlapati Railway Station, and multiple internal colony roads, containing a mix of fast-moving traffic and slow-speed manoeuvres associated with parking, dropping students off at school, and commercial activities. Therefore, the site's selection was based on a structured GIS-based analysis and reasonable evidence from the local police, as it pertains to accidents that occurred in the police jurisdiction.

CHAPTER 5

SURVEY DESIGN AND METHODOLOGY

5.1 Study Design Framework

The study adopts a mixed-method approach, combining both qualitative and quantitative techniques to analyse traffic conditions and pedestrian safety, particularly within school zones. The framework is designed to systematically assess existing conditions, identify key issues, and develop appropriate planning and design interventions. It follows a structured, step-by-step process that begins with the identification of the study area, including the school zone and its surrounding road network, followed by a preliminary assessment through a reconnaissance survey. Subsequently, both primary and secondary data are collected and analysed to understand traffic patterns, user behaviour, and infrastructure conditions. This analysis helps in identifying conflict zones and major safety concerns, which then inform the development of suitable planning and design solutions. Overall, the framework ensures that the study remains data-driven, evidence-based, and context-sensitive, making it highly relevant for urban street design and pedestrian safety improvement.

5.2. Design of Questionnaire

A structured questionnaire was designed to collect primary data from road users and key stakeholders in the study area. The questionnaire aimed to understand travel behaviour, safety perception, and the issues experienced by users on a daily basis. It was divided into several sections, including user profile (age, gender, and occupation), travel characteristics (mode of transport), safety perception (sense of safety and any accident experiences), infrastructure-related issues (such as the condition of footpaths, availability of crossings, parking problems, and encroachments), and suggestions for improvement. Both closed-ended and open-ended questions were incorporated to facilitate easy quantitative analysis while also capturing detailed qualitative insights and user opinions.

5.3. Field Survey and Data Acquisition

Field surveys were conducted to collect on-ground data related to traffic, pedestrian movement, and street conditions. The data collection process was divided into three stages:

5.3.1 Reconnaissance survey

A preliminary reconnaissance survey was conducted to understand the general characteristics of the study area. This involved identifying key activity generators such as schools, shops, and street vendors, examining the road geometry and layout, observing traffic flow patterns, and assessing the presence and condition of pedestrian infrastructure. The insights gained from this initial survey were instrumental in finalizing the survey locations, determining peak observation hours, and selecting appropriate methods for detailed data collection.

5.3.2. Detailed field survey

A detailed field survey was conducted to collect quantitative and spatial data related to the physical and functional characteristics of the study area. This included measuring road width, carriageway, and footpath dimensions, identifying the location of intersections and pedestrian crossings, and documenting encroachments such as street vendors and parked vehicles. The survey also captured the location of informal activities, including gumtis and hawkers, which influence traffic movement and pedestrian safety. Data collection was carried out using total stations, measuring tape, mobile GPS for location referencing, and photographic documentation to support analysis and mapping.

5.3.3. Traffic observation

Traffic observations were conducted during peak school hours, specifically during morning arrival and afternoon dispersal periods, to capture the most critical traffic conditions. The data recorded included traffic volume classified by vehicle type such as cars, two-wheelers, auto-rickshaws, and cycles, along with patterns of pedestrian movement and crossing behaviour. In addition, conflict points between vehicles and pedestrians were identified and documented, and on-street parking and vehicle stoppage patterns were observed. This helped in understanding the interaction between different road users and identifying areas of congestion and safety concern.

5.4. Primary Data

Primary data was collected directly from the field to understand real-time conditions and user behaviour.

5.4.1. Surveys

Surveys were conducted among students and teachers of the institutes to gather insights into daily travel experiences and safety concerns within the study area. The survey aimed to understand travel patterns to and from the school, including commonly used modes of transport. It also focused on identifying safety concerns faced by users, particularly in relation to traffic conditions, as well as issues associated with congestion and pedestrian movement. The responses provided valuable input for assessing user needs and highlighting critical problem areas in the school zone. The following figure 39, figure 40, figure 41, figure 42, figure 43, figure 44, figure 45 and figure 46 were captured during the survey to document the interaction with principal, teachers and students.



Figure 39. Interaction with principal of Kendriya Vidyalaya Number 2 (Author)



Figure 40. Interaction with students of Kendriya Vidyalaya Number 2 (Author)



Figure 41. Interaction with principal of Sarojini Naidu Government Girls School (Author)



Figure 42. Interaction with students of Sarojini Naidu Government Girls School (Author)



Figure 43. Interaction with teachers of Subhash Excellence Government Higher Secondary School (Author)



Figure 44. Interaction with students of Subhash Excellence Government Higher Secondary School (Author)



Figure 45.Interaction with students of Government Women's (Author)



Figure 46. Interaction with students and teachers of Nutan College (Author)

5.4.2 Observations

Field observations were conducted to record key on-ground conditions and user behaviour within the study area (as shown in figure 47, figure 48, figure 49, figure 50, 51 and figure 52).



Figure 47. Untidy sidewalk with plants and garbage (Author)



Figure 48. Unavailability of footpath (Author)

This included identifying pedestrian desire lines, which represent informal crossing paths, observing traffic conflicts at intersections, analysing driver behaviour near the school zone, and documenting the presence and activity of vendors and hawkers. These observations provided valuable insights into real-time movement patterns and interactions, helping to identify unsafe practices and locate high-risk zones requiring intervention.



Figure 49. Students walking on road due to unavailability of footpath (Author)



Figure 50. School Bus parking on road (Author)



Figure 51. Congestion during school closing time (Author)



Figure 52. Congestion due to encroachment on road (Author)

5.5 Secondary Data

Secondary data was collected from institutional and official sources to support primary findings.

5.5.1. School Records

Data obtained from school authorities included information on the number of students and staff, school timings corresponding to peak traffic periods.

School timing:

a) Subhash Government Higher Secondary School: 9 am to 2 pm

b) Kendriya Vidyalaya No. 02: 8 am to 2 pm
c) Sarojini Naidu Government Girls Higher Secondary School: 10 am to 4:30 pm
d) Government Women's Polytechnic College: 10 am to 5 pm
e) Sarojini Naidu Government Girl's Post Graduate College: 10 am to 5 pm

This information helped in estimating traffic volume and peak hour intensity within the study area.

5.5.2. Accident Data

Accident data was collected from local authorities and police records to understand the safety conditions within the study area. This included information on the number of accidents, along with their type and severity, as well as the time and location of occurrence. The analysis of this data helped in identifying accident-prone locations and understanding patterns related to road safety, thereby supporting the identification of critical risk zones for intervention.

5.6 Tools and Techniques Used

The study utilized a combination of digital and manual tools for effective data collection and analysis. Software such as AutoCAD was used for base map preparation and spatial mapping, while Geographic Information System (QGIS) supported spatial analysis and the mapping of conflict zones. Microsoft Excel was employed for data tabulation, organization, and basic statistical analysis. In addition, field tools such as measuring tape, mobile GPS devices, and cameras were used for on-site measurements and documentation. Together, these tools ensured accurate representation, reliable data analysis, and effective visualization of spatial and traffic conditions within the study area.

CHAPTER 6

DATA ANALYSIS

The primary survey was conducted to understand user behaviour, travel patterns, and on-ground issues at the study junction. The survey included pedestrians, cyclists, street vendors, and vehicle users. The data collected through the survey was analysed to understand the existing conditions and user experiences around the school area. Responses were collected, compiled and interpreted using simple statistical methods such as mean score analysis for Likert scale questions and then converting it into graphs and charts. This analysis helped in identifying common patterns, key safety concerns, and the overall perception of students and staff regarding road safety and pedestrian conditions near the school. The findings from the data analysis provided a clear base for understanding problem areas and supported the need for appropriate school zone interventions.

6.1 Demographic profile and mode of travel analysis

The primary survey was conducted across five educational institutions located in Shivaji Nagar, Bhopal, with the objective of understanding user characteristics, travel behaviour, and safety concerns in the school zone area.

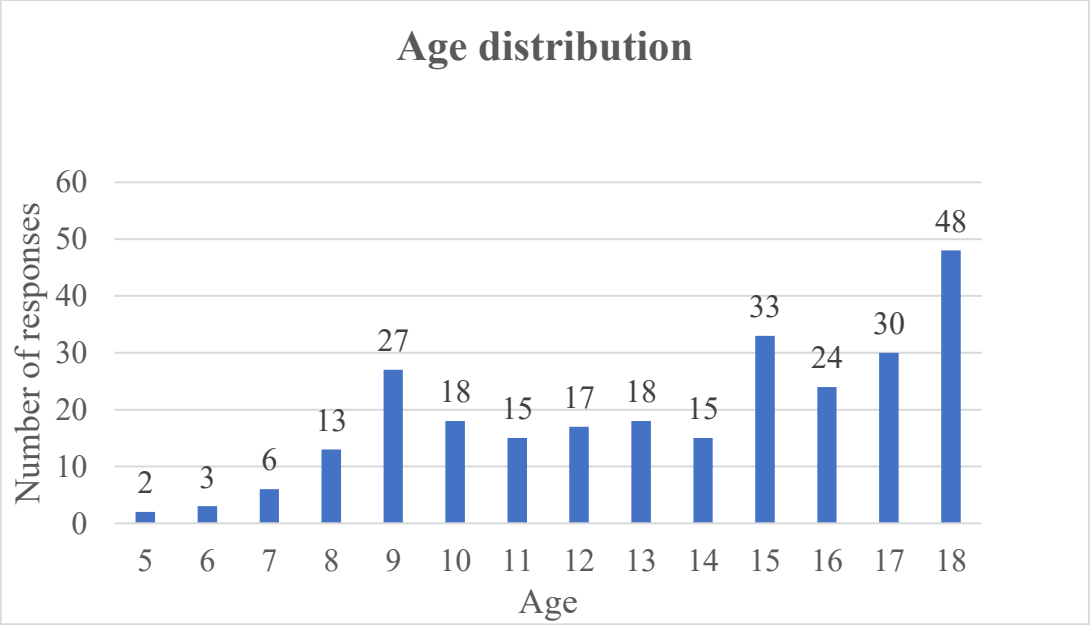


Figure 53. Age Distribution (Author)

A total of 269 responses were collected from students ranging from primary to higher education levels, along with 60 responses from teachers. The data was collected through a combination of physically administered questionnaires and online forms, ensuring a wide and inclusive participation.

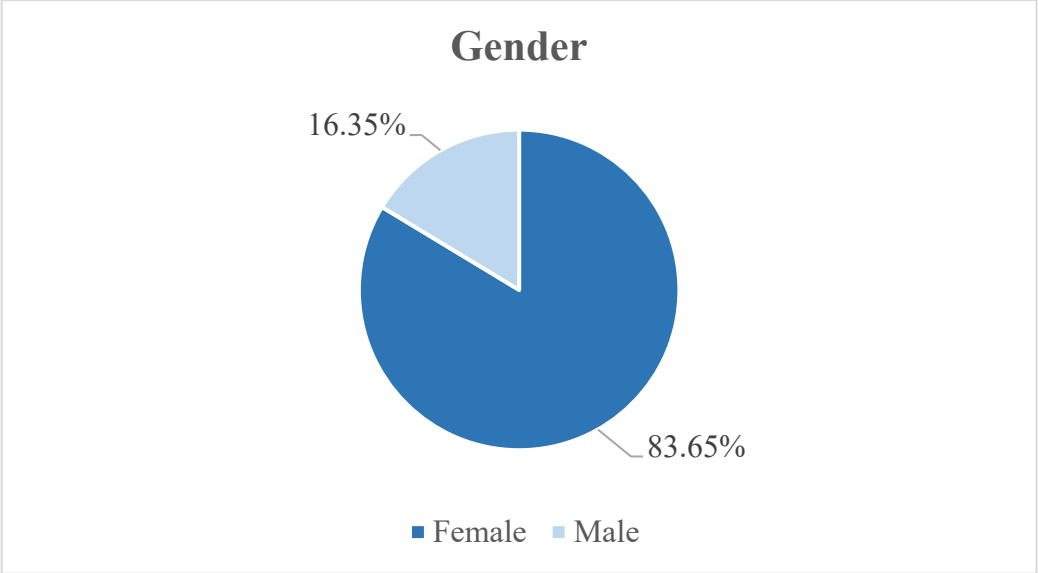


Figure 54. Gender distribution (Author)

The analysis of the demographic profile indicates that the majority of respondents belong to adolescent age groups (as shown in figure 53), highlighting the presence of a highly vulnerable population exposed to daily traffic conditions.

The gender distribution shows a higher proportion of female respondents (as shown in figure 54), which further emphasizes the need for gender-sensitive safety planning in the study area.

As shown in figure 55, in terms of travel behaviour, the data indicates that informal transport modes, particularly auto and shared vehicles, dominate the modal share. At the same time, a significant proportion of students rely on walking and cycling as their primary modes of travel. The use of private vehicles is minimal, reflecting the localized nature of trips and the dependency on affordable and accessible transport options.

However, this modal distribution presents several challenges. The heavy reliance on informal transport contributes to unmanaged congestion, particularly during peak

school hours. At the same time, students who walk or cycle are exposed to unsafe conditions due to the absence of dedicated infrastructure such as footpaths and cycle tracks. The coexistence of multiple modes within limited road space creates a mixed traffic environment, increasing the likelihood of conflicts between pedestrians and vehicles.

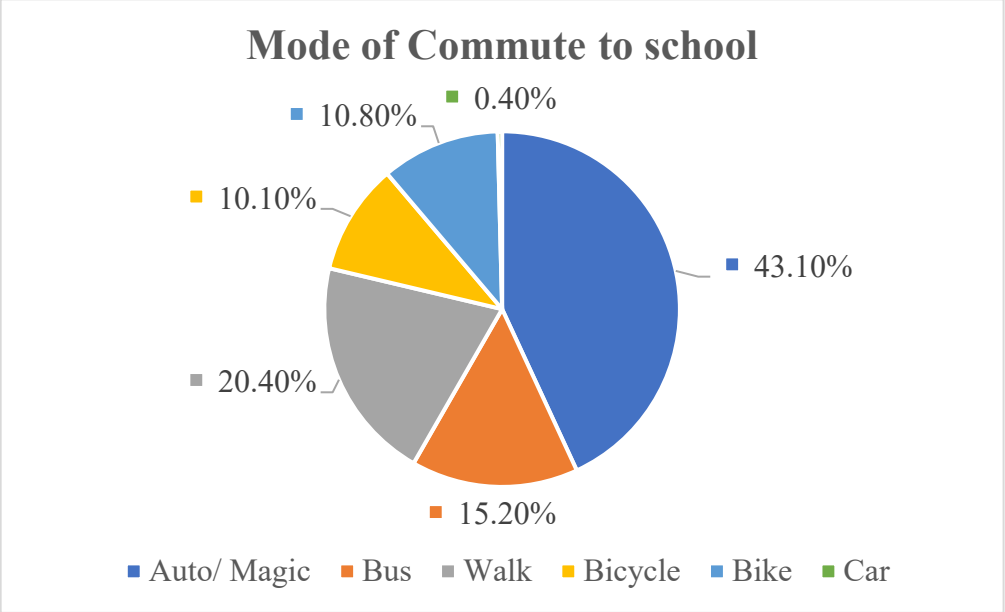


Figure 55. Mode of commute to school (Author)

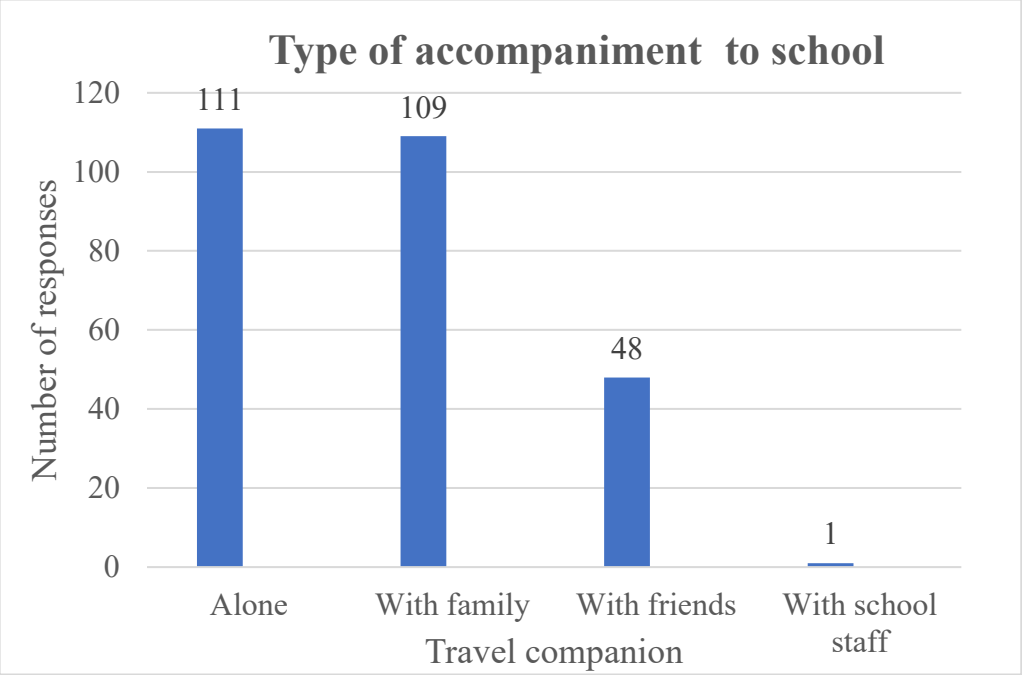


Figure 56. Type of accompaniment to school (Author)

Additionally, as shown in figure 56, a considerable number of students travel independently, without adult supervision, which increases their exposure to unsafe traffic conditions

Overall, the survey results indicate that the study area is characterized by a concentration of young, vulnerable users who rely heavily on informal and non-motorized transport modes, making safety and infrastructure provision a critical concern.

6.2 Safety Perception Analysis

The safety perception analysis was carried out using responses collected through Likert scale-based questions and user feedback regarding their daily experiences in the school zone area.

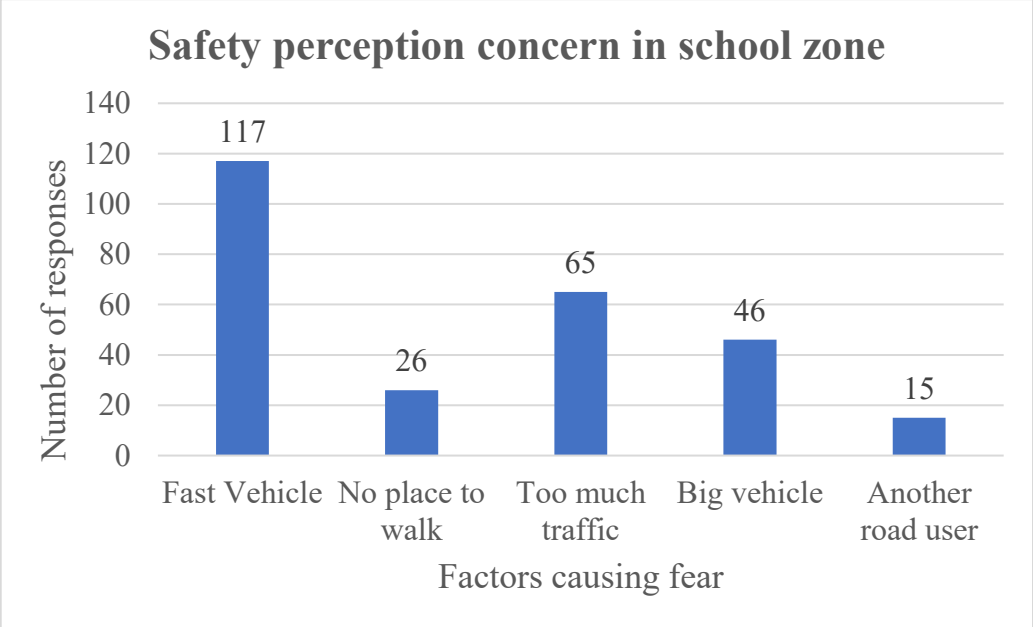


Figure 57. Safety perception concern in school zone (Author)

The major safety concerns identified by the respondents include fast-moving vehicles, heavy traffic congestion, the presence of large vehicles, and the lack of adequate walking space (as shown in figure 57).

The findings indicate that a large proportion of respondents perceive vehicle speeds near the school as excessively high (as shown in figure 58). This reflects a serious issue of over-speeding, which significantly contributes to unsafe conditions for

pedestrians, especially children. These factors collectively create an environment where pedestrians feel unsafe and vulnerable.

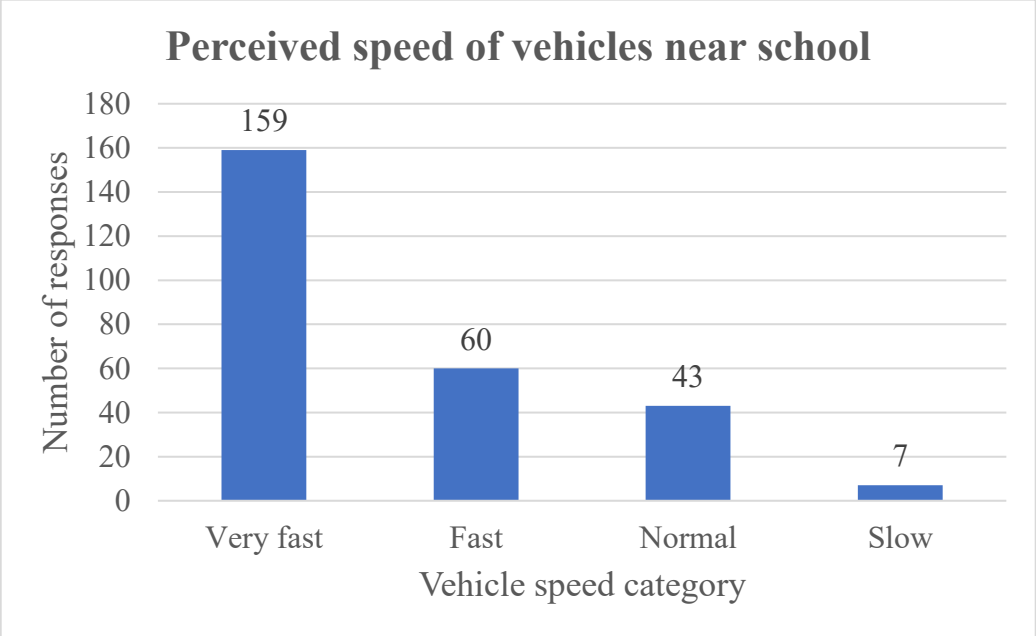


Figure 58. Perceived speed of vehicles near school (Author)

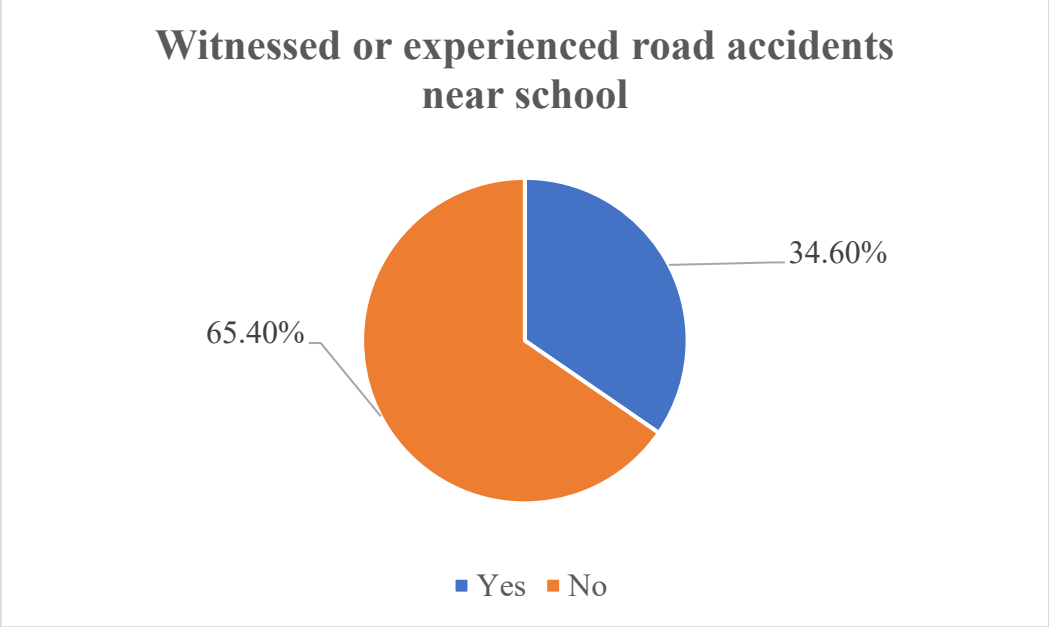
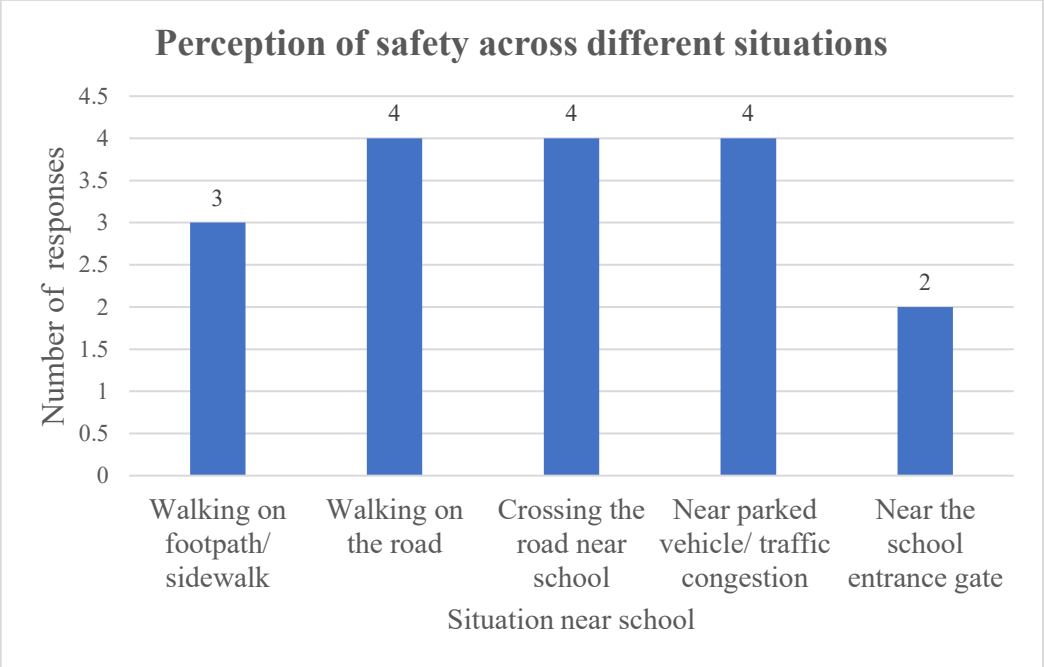


Figure 59. Witnessed or experienced road accidents near school (Author)

Additionally, from figure 59, a notable number of respondents reported having witnessed or experienced road accidents in the vicinity of the school, indicating the presence of conflict-prone conditions.



Safety levels (1= Very safe, 2= Safe, 3= Neither Safe nor unsafe, 4= Unsafe, 5= Very unsafe)

Figure 60. Perception of safety across different situation (Author)

The perception of safety varies across different situations within the school environment. As shown in figure 60, students feel walking on designated footpaths is perceived as relatively safer compared to walking on the carriageway. However, in the absence of continuous footpaths, many pedestrians are forced to walk on the road, which significantly increases their risk. Crossing the road near the school and navigating through congested areas with parked vehicles are perceived as particularly unsafe. In contrast, areas near the school entrance gate show relatively better safety perception, suggesting localized improvements but overall inadequate conditions.

Responses from teachers further reinforce these findings, as they also reported difficulties in walking and strongly agreed on the need for safety improvements (as shown in figure 61).

The analysis clearly indicates a consistent perception of unsafe conditions among both students and teachers, driven by high vehicle speeds, lack of pedestrian infrastructure, and unmanaged traffic conditions.

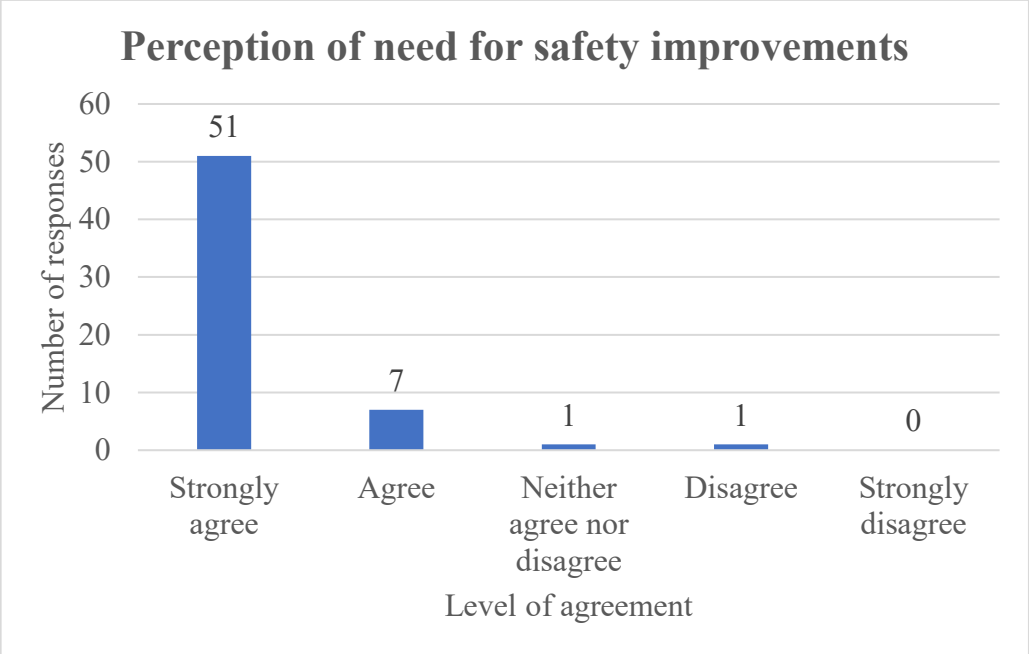


Figure 61. Perception of need for safety improvements (Author)

6.3 Infrastructure Assessment

The infrastructure assessment was carried out based on both field observations and user responses obtained from the survey. The findings reveal several critical deficiencies in the existing road environment around the school area. One of the major issues identified is the lack of continuous and dedicated pedestrian infrastructure. In many locations, footpaths are either absent or obstructed, forcing pedestrians to walk on the carriageway.

The absence of safe and designated crossing facilities further aggravates the situation. There are no clearly marked pedestrian crossings or refuge islands, making it difficult and unsafe for students to cross the road, especially during peak hours. In addition, the study area lacks effective traffic calming measures, which contributes to high vehicle speeds and increases the risk of accidents.

Traffic congestion is another significant concern, primarily caused by the concentration of informal transport modes, on-street parking, and peak-hour school activities such as pick-up and drop-off. These conditions create a chaotic traffic environment, leading to frequent conflicts between vehicles and pedestrians.

Overall, the infrastructure assessment highlights that the existing road environment is inadequate and unsafe, particularly for children. The findings strongly support the need for implementing structured school zone measures, including pedestrian-friendly infrastructure, traffic calming strategies, and better traffic management practices in accordance with relevant guidelines.

6.4 Pedestrian Volume and Peak Hour Analysis

6.4.1 Analysis of Site 01

A] Site Characteristics and Data Collection

The pedestrian survey was conducted near the Sarojini Naidu Government Girl's Post Graduate College (as shown in figure 62). The data collection spanned a 12-hour period on October 14, 2025, from 06:00 AM to 18:00 PM. The primary objective was to quantify pedestrian volumes, identify peak demand periods, and analyse the directional distribution of flow (Entry vs. Exit) to assess the level of service and infrastructure requirements at this junction. During the 12-hour observation period, a total of 3,724 pedestrians were recorded navigating the junction. The average flow rate was calculated at approximately 310 pedestrians per hour.



Figure 62. CCTV Footage captured for Pedestrian data collection at site 01 (Data Corp Traffic)

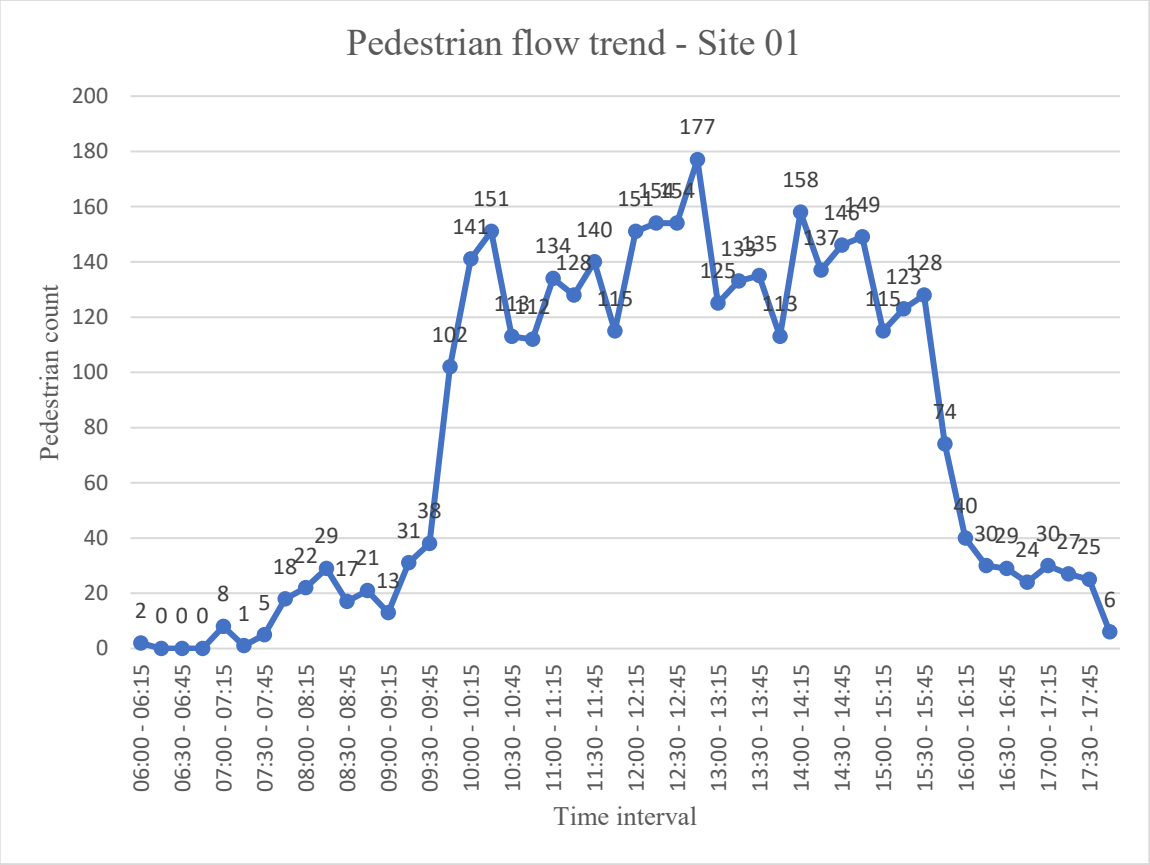


Figure 63. Pedestrian flow trend – Site 01 (Author)

B] Temporal Variation and Peak Hour Analysis

The analysis identifies a significant "Mid-Day Peak", which deviates from standard morning/evening commute patterns often seen in institutional zone.

i. **Peak Hour:** The peak hour occurred between 12:00 PM and 13:00 PM, with a total volume of 636 pedestrians. This single hour accounts for approximately 17.07% of the total daily recorded volume.

ii. **Peak 15-Minute Interval:** The highest intensity of movement was recorded between 12:45 PM and 13:00 PM, with 177 pedestrians entering or exiting the college (as shown in figure 63).

iii. **Peak Hour Factor (PHF):** To measure the uniformity of flow during the peak hour, the Peak Hour Factor was calculated as follows:

$$PHF = V/(4*V_{15}) = 636/(4*177) \approx 0.90$$

A PHF of 0.90 indicates a relatively stable and consistent pedestrian flow during the peak period, suggesting that the junction operates near its observed capacity for the duration of the hour rather than experiencing a short, unsustainable spike.

C] Key Findings and Results

The analysis of the pedestrian data at the location yields the following conclusions:

i. **Non-Commuter Peak:** The dominance of the period from 12:00 PM to 13:00 PM peak suggests the area is heavily influenced by institutional activity rather than traditional home-to-work morning commutes.

ii. **Capacity Requirements:** Infrastructure planning should be based on the peak 15-minute flow (177 peds/15-min). To maintain a comfortable Level of Service (LOS), sidewalk widths and crossing timings must accommodate this localized density.

iii. **Low Early-Hour Utility:** The near-zero volume before 07:00 AM indicates that early-morning pedestrian infrastructure (such as specialized lighting or security) may be optimized for later operational hours.

6.4.2 Analysis of Site 02

A] Site Characteristics and Data Collection



Figure 64. CCTV Footage captured for Pedestrian data collection at site 02 (Data Corp Traffic)

The pedestrian survey was conducted near Sarojini Naidu Government Girls Higher Secondary School (as shown in figure 64). Data was collected on October 14, 2025, for a 12-hour period from 06:00 AM to 18:00 PM. This location is of particular analytical interest due to the high homogeneity of its user base.A total of 1,439 pedestrians were recorded over the survey duration. While the total volume is moderate, the distribution of this volume is highly concentrated in specific time windows, indicating institutionalized movement patterns.

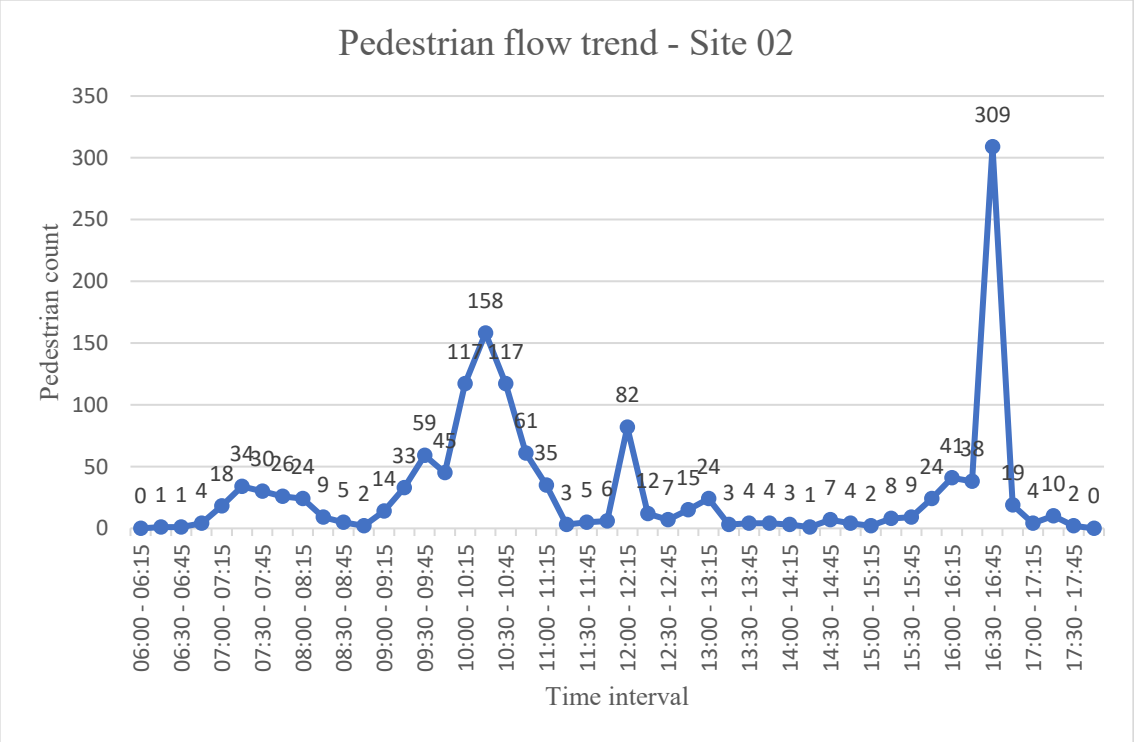


Figure 65. Pedestrian flow trend - Site 02 (Author)

B] Temporal Variation and Peak Hour Analysis

The location exhibits two primary surges, aligning with standard educational institution timings (start of day and end of sessions).

i. **Peak Hour:** The morning peak hour occurred between 10:00 AM, and 11:00 AM, with 453 pedestrians.

ii. **Secondary Surge:** A significant afternoon surge was noted between 16:30 PM and 16:45 PM, which recorded 309 pedestrians in just 15 minutes (as shown in figure 65).

iii. Peak Hour Factor (PHF):

PHF= 453/ (4*158) ≈ 0.72

A PHF of 0.72 suggests moderate clustering, typical of students arriving or departing in groups as classes end.

C] Demographic and Composition Analysis

The demographic data for Junction 04 is the most striking aspect of the site:

i. **Gender Dominance:** The pedestrian flow is 94.1% female (1,354 females vs. 85 males).

ii. **User Category:** 84.2% of the users are classified as students, while only 15.8% are adults.

D] Key Findings and Results

i. **Institutional Influence:** The overwhelming presence of female students 94% and the specific timing of the peaks strongly indicate that this junction serves a female educational institution.

ii. **Safety and Mobility Implications:** Given that the vast majority of users are female students, urban design at this junction should prioritize high-visibility crossings, wider waiting areas to accommodate group movements, and enhanced safety lighting.

iii. **Surge Management:** The 15-minute spike at 16:30 PM i.e. 309 pedestrians are nearly as high as the entire preceding hour's volume. This "shock load" on the infrastructure requires pedestrian signals or traffic wardens to manage the sudden influx.

6.4.3 Analysis of Site 03

The pedestrian survey was conducted near Government Women's Polytechnic College (as shown in figure 66). The data collection occurred on October 14, 2025, for a 12-hour period between 06:00 AM and 18:00 PM. The survey captured detailed demographic data, categorizing pedestrians by age group (Adult/Student) and gender. A total of 458 pedestrians were recorded at the location during the 12-hour survey. The average flow rate is approximately 38 pedestrians per hour.



Figure 66. CCTV Footage captured for Pedestrian data collection at site 03 (Data Corp Traffic)

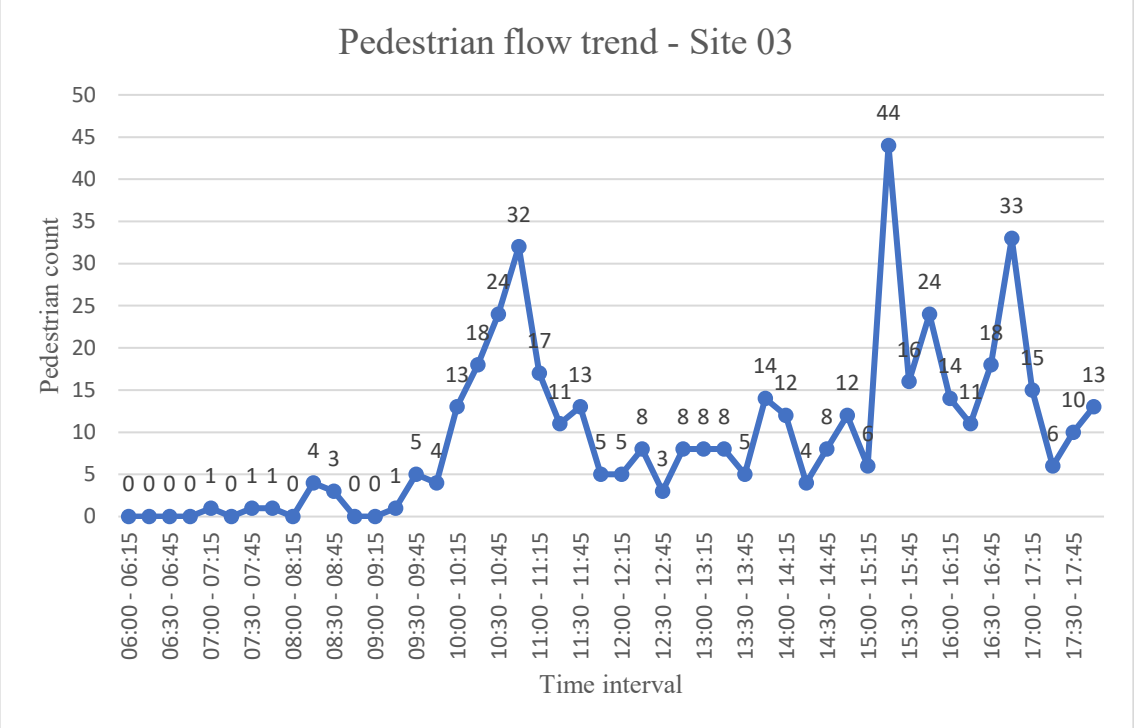


Figure 67. Pedestrian flow trend – Site 03 (Author)

A] Site Characteristics and Data Collection

B] Temporal Variation and Peak Hour Analysis

The flow at the location remains very low during the morning and early afternoon, with a significant surge occurring later in the day.

i. **Peak Hour:** The peak hour was recorded between 15:00 PM and 16:00 PM, with a total of 90 pedestrians.

ii. **Peak 15-Minute Interval:** The highest intensity of movement occurred between 15:15 PM and 15:30 PM, with 44 pedestrians (as shown in figure 67).

iii. **Peak Hour Factor (PHF):**

PHF= 90/ (4*44) ≈ 0.51

A PHF of 0.51 indicates a highly peaked flow. Nearly half of the entire peak hour's traffic occurred in a single 15-minute window, suggesting a "departure surge" likely linked to institutional or school timings.

C] Demographic and Composition Analysis

The demographic data suggests that the location serves as a corridor for an educational or student-heavy area:

i. **Gender Distribution:** The flow is predominantly female, accounting for **81.9%** of the total volume (375 females vs. 83 males).

ii. **User Category:** Students represent the majority of users at **69.2%**, while adults make up **30.8%**.

D] Key Findings and Results

i. **Late-Day Activity Surge:** Unlike Junction 04 (which had a morning peak), Junction 05 peaks in the mid-afternoon (15:00 PM). This suggests it may be a route used more for returning trips or after-school activities.

ii. **Peaked Departure Patterns:** The low PHF (0.51) highlights that the infrastructure needs to handle sudden, short-lived bursts of pedestrians rather than a steady stream.

iii. **High Student Utility:** With nearly 70% of users being students, safety measures such as school-zone signage will be highly effective.

6.4.4 Analysis of Site 04



Figure 68. CCTV Footage captured for Pedestrian data collection at site 04 (Data Corp Traffic)

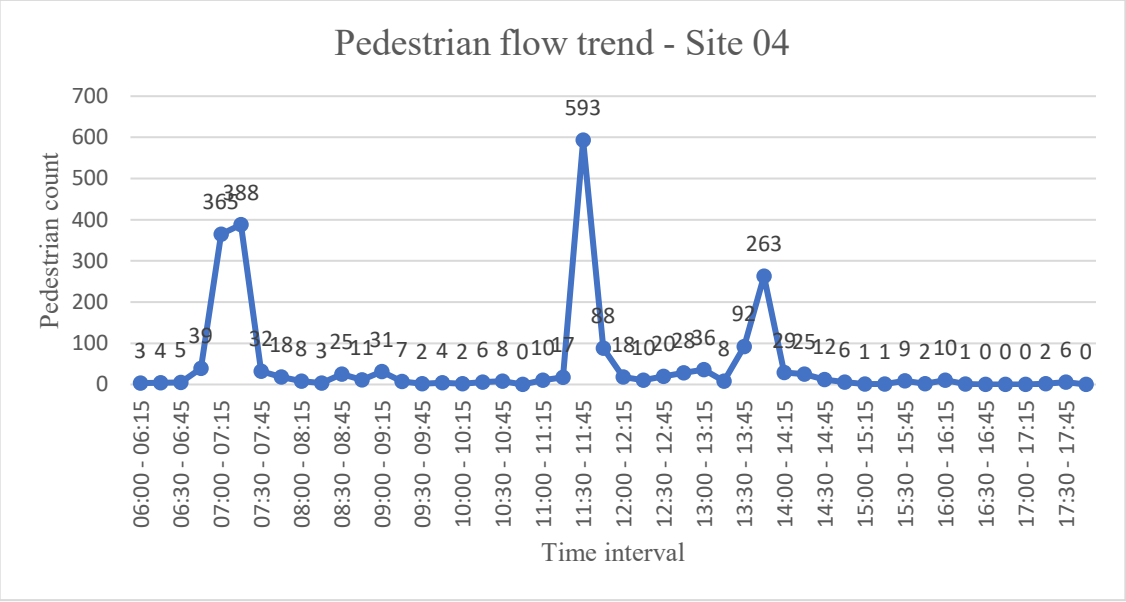


Figure 69. Pedestrian flow trend - Site 04 (Author)

A] Site Characteristics and Data Collection

The pedestrian survey was conducted near Kendriya Vidyalaya No. 02 (as shown in figure 68) on October 14, 2025. Unlike the previous junction-based surveys, this “Mid-Block” location captures continuous flow along a specific segment of the sidewalk/roadway, providing a clearer picture of corridor capacity and

throughput. This location recorded a high volume of 2,248 pedestrians over the 12-hour period. This represents one of the most active corridors surveyed, with an average hourly flow of 187pedestrians.

B] Temporal Variation and Peak Hour Analysis

The temporal distribution at the location is heavily skewed toward the early morning, followed by another sharp peak near midday.

i. **Peak Hour:** The morning peak hour occurred between 07:00 AM and 08:00 AM, recording 803 pedestrians. This accounts for 35.7% of the total daily traffic in a single hour.

ii. **Peak 15-Minute Interval:** A second massive surge occurred between 11:30 and 11:45, with 593 pedestrians passing through in just 15 minutes (as shown in figure 69).

iii. **Peak Hour Factor (PHF):**

PHF= 803/ (4*388) ≈ 0.52

A PHF of 0.52 confirms a highly concentrated arrival pattern, typical of a school start time or a shift change at a large facility.

C] Demographic and Composition Analysis

The demographic data reinforces the “Institutional Access” theory for this site:

i. **User Category:** 84.1% of the total volume consists of students, while only 15.9% are adults.

ii. **Gender Distribution:** The flow is almost perfectly balanced, with 51.1\% female and 48.9% male pedestrians.

D] Key Findings and Results

i. **High-Intensity Morning Corridor:** The surge of 800+ pedestrians at 07:00 AM indicates this is a primary commuter/student artery. The physical width of the sidewalk at this “mid-block” point is critical to prevent spillover onto the active roadway.

ii. **Mid-Day Shock Load:** The 15-minute window starting at 11:30 AM (593 pedestrian) is the highest intensity recorded across all surveyed sites. This suggests a major synchronized release of students.

iii. **Gender Neutrality:** Unlike other location, this site shows a balanced gender ratio, suggesting it serves a co-educational or general-purpose area.

CHAPTER 7

PROPOSALS

This chapter presents the proposed school zone improvement plan for the institutional corridor surrounding major educational institutions within the study area. The proposal has been developed based on traffic analysis, pedestrian movement studies, field surveys, and spatial assessment carried out during the earlier stages of the study. The chapter focuses on developing a safe, accessible, and pedestrian-friendly environment for students and other road users within the institutional precinct.

The proposal adopts a pedestrian-oriented and child-friendly planning approach aimed at improving mobility, accessibility, traffic management, and streetscape quality. The intervention strategy includes measures such as raised pedestrian crossings, traffic calming treatments, improved sidewalks, junction redesign, signage, street enhancement, and public transport integration in accordance with IRC SP:32 guidelines and complete street principles.

Based on the analysis, critical intervention locations identified as Locations A to G have been selected for detailed design proposals. These interventions aim to improve pedestrian safety, regulate vehicular movement, reduce traffic conflicts, and enhance the overall functionality and walkability of the school zone corridor.

7.1 Existing Scenario and Problem Identification

7.1.1 Existing Plan of School Zone

The existing plan as shown in figure 70 illustrates the current spatial and transportation conditions within the school zone surrounding the educational institutions in the study area. The corridor experiences significant pedestrian and vehicular movement throughout the day, particularly during school arrival and dispersal hours, due to the concentration of schools and colleges located within close proximity.

The road network is characterized by multiple junctions, curved road segments, irregular intersection geometry, and continuous vehicular flow, resulting in several pedestrian-vehicle conflict points. Existing issues include discontinuous sidewalks, inadequate pedestrian crossings, insufficient traffic calming measures, informal parking

activities, and unsafe pedestrian crossing behaviour, which reduce the overall safety and accessibility of the corridor.

Most junctions within the study area function primarily as vehicle-oriented spaces with limited pedestrian priority and inadequate traffic regulation measures. The analysis of existing conditions highlights the need for integrated interventions focusing on pedestrian safety, organized circulation, traffic calming, accessibility enhancement, and streetscape improvement within the school zone environment.

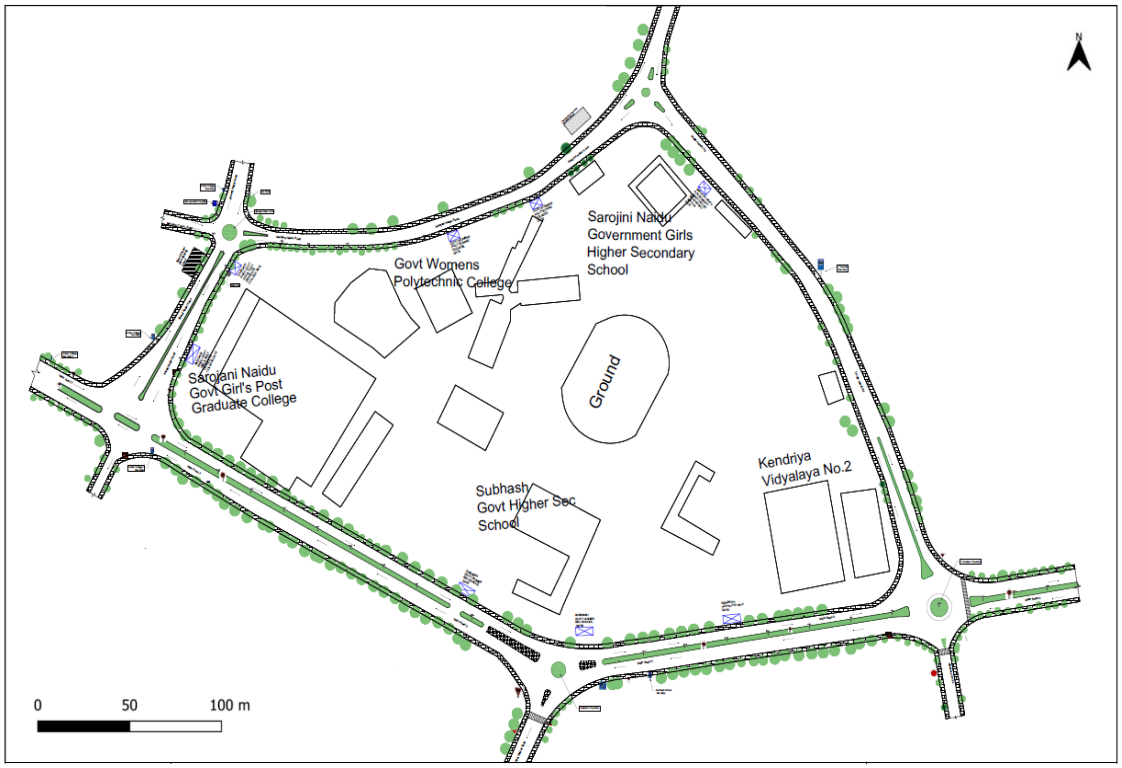


Figure 70. Existing plan of school zone (Author)

7.1.2. Issues Identified in the Study Area

The detailed analysis of the study area identifies several issues affecting the safety, accessibility, and functionality of the school zone environment. High pedestrian-vehicular conflicts, unsafe road crossing behaviour, inadequate pedestrian crossings, and insufficient traffic calming measures create unsafe conditions, particularly during school peak hours. High vehicular speeds near institutional entrances further increase safety risks for students and other vulnerable road users.

The study area also experiences discontinuous sidewalks, irregular junction geometry, uncontrolled turning movements, informal parking activities, and inadequate public transport integration, which reduce overall walkability and accessibility. The absence of pedestrian-priority and child-friendly planning elements further affect the efficiency and safety of the institutional corridor.

The identified issues highlight the need for an integrated school zone improvement strategy focused on pedestrian safety, traffic calming, junction redesign, organized circulation and accessibility enhancement in accordance with complete street and child-friendly planning principles.

7.2. Proposed School Zone Improvement Strategy

7.2.1. Pedestrian Safety and Accessibility Strategy

Pedestrian safety forms the primary focus of the proposed intervention strategy due to the high pedestrian movement generated by the surrounding educational institutions. The proposal introduces designated pedestrian crossings, raised pedestrian crossings, continuous sidewalks, and organized pedestrian circulation systems to improve accessibility and reduce pedestrian-vehicle conflicts within the school zone.

Pedestrian crossings have been strategically proposed near institutional gates, bus stops, junctions, and major pedestrian desire lines to facilitate safer road crossing for students and pedestrians.

7.2.2. Traffic Calming and Speed Management Strategy

The proposal incorporates various traffic calming measures aimed at regulating vehicular movement and reducing operating speeds within pedestrian-intensive institutional areas. The interventions include rumble strips, textured pavement treatments, reduced speed limit signage, school ahead warning signs, stop lines, gateways, and raised pedestrian crossings to improve driver awareness and traffic discipline within the school zone.

The strategy also focuses on improving junction safety through organized vehicular circulation and controlled traffic movement patterns. These measures collectively help reduce pedestrian-vehicle conflicts, improve operational safety, and

create a safer traffic environment for students, pedestrians, and other vulnerable road users within the study area.

7.3. Identification of Critical Intervention Locations

7.3.1 Basis for Selection of Intervention Locations

The identification of critical intervention locations within the study area was carried out through detailed field surveys, traffic observations, pedestrian movement analysis, and spatial assessment of the institutional corridor. The selection process focused on areas experiencing high pedestrian-vehicular interaction, unsafe traffic conditions, inadequate pedestrian infrastructure, and operational deficiencies affecting the safety and accessibility of the school zone environment.

Several parameters such as pedestrian concentration, traffic volume, conflict points, unsafe crossing behaviour, congestion during peak school hours, visibility constraints, and lack of traffic calming measures were considered while selecting intervention locations. Areas with high pedestrian demand and frequent interaction between students and moving vehicles were prioritized for detailed design proposals.

The assessment also considered the spatial relationship between institutional entrances, bus stops, junctions, and major pedestrian desire lines to ensure that the proposed interventions effectively improve accessibility, circulation, and pedestrian safety within the corridor network.

7.3.2. Identification of Locations A to G

Based on the analysis, seven critical intervention locations identified as Locations A to G were selected (as shown in figure 71) for detailed proposal development within the study area. These locations represent important junctions, institutional access corridors, and pedestrian movement zones requiring targeted traffic management and pedestrian safety improvements.

Location A and Location G were identified as major institutional junctions experiencing complex vehicular turning movements, high pedestrian concentration, and inadequate pedestrian crossing infrastructure. These locations function as significant access points for educational institutions and public transport facilities, resulting in increased traffic conflicts and unsafe pedestrian conditions during peak activity hours.

Location B represents a major traffic convergence point characterized by irregular junction geometry, continuous vehicular movement, and high pedestrian activity near school gates and bus stops. The lack of organized crossing infrastructure and traffic calming measures at this location contributes toward operational conflicts and reduced pedestrian safety.

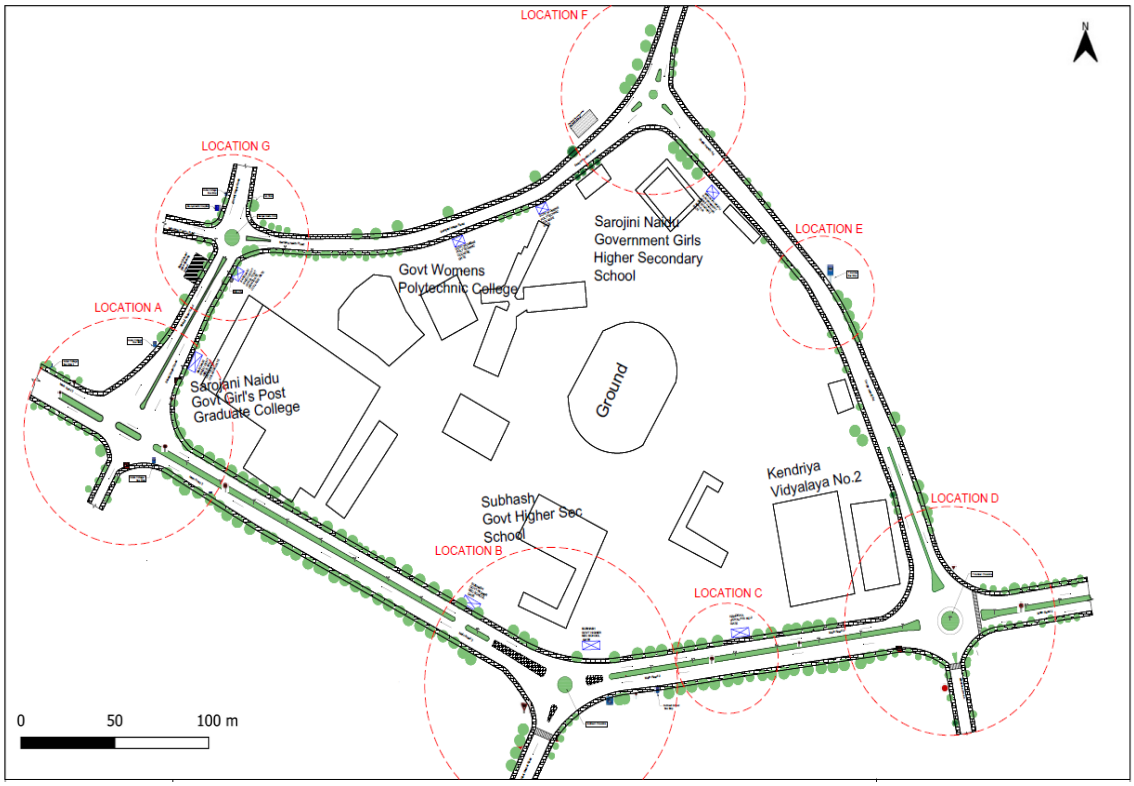


Figure 71. Identification of priority intervention area (Author)

Location C was identified as an important school access corridor adjacent to Kendriya Vidyalaya No. 02, where high vehicular speeds and inadequate pedestrian crossing facilities create unsafe conditions for students accessing the school gate. The location required interventions focused on speed management and improved pedestrian visibility.

Location D represents a rotary junction accommodating traffic movement from multiple connecting roads. The junction experiences high traffic convergence and continuous vehicular circulation, creating operational conflicts and insufficient pedestrian priority conditions at intersection approaches.

Location E was identified as a corridor segment requiring improvement in pedestrian accessibility and public transport integration. The absence of designated pedestrian crossing infrastructure near bus stop facilities creates unsafe conditions for pedestrians and students crossing the roadway.

Location F represents a critical curved junction area characterized by visibility constraints, irregular traffic movement, and inadequate pedestrian protection measures. The location required interventions aimed at improving junction organization, circulation efficiency, and pedestrian safety.

7.3.3. Priority Intervention Areas

The selected intervention locations collectively represent the most critical safety and accessibility concern areas within the school zone environment. These locations were prioritized due to their direct impact on student movement, pedestrian accessibility, and overall corridor safety within the institutional precinct.

The intervention areas primarily include junctions, institutional gateways, pedestrian crossing zones, and public transport access points where the interaction between pedestrians and vehicular traffic is highest. These locations also exhibit inadequate traffic regulation, insufficient pedestrian infrastructure, and poor spatial organization affecting the efficiency and safety of movement within the study area.

The prioritization of these locations ensures that the proposed interventions address the most vulnerable and high-conflict areas while contributing toward the development of a safer and more organized school zone circulation network.

7.3.4. Need for Detailed Design Interventions

The analysis of the identified intervention locations highlights the urgent need for comprehensive design interventions focused on pedestrian prioritization, traffic calming, junction management, and accessibility enhancement. Existing conditions within the selected locations reveal the absence of integrated school zone planning measures suitable for high pedestrian activity areas surrounding educational institutions.

The proposed interventions therefore focus on improving pedestrian crossing safety, reducing vehicular speeds, organizing traffic circulation, enhancing public transport accessibility, and strengthening the overall streetscape quality within the study

area. Detailed design proposals for each location have been developed based on site-specific conditions, movement patterns, and safety requirements.

The identified intervention locations collectively form the basis for implementing an integrated school zone improvement strategy aimed at creating a safer, more accessible, and pedestrian-friendly institutional environment.

7.4. Detailed Design Proposals

7.4.1. Location A - Existing Condition

Location A represents a critical junction area situated adjacent to Sarojini Naidu Government Girls Post Graduate College (as shown in figure 72), where multiple road segments intersect and generate significant pedestrian and vehicular interaction. The junction functions as an important access point for students, public transport users, and local traffic movement, resulting in increased congestion and traffic conflicts during institutional peak hours.

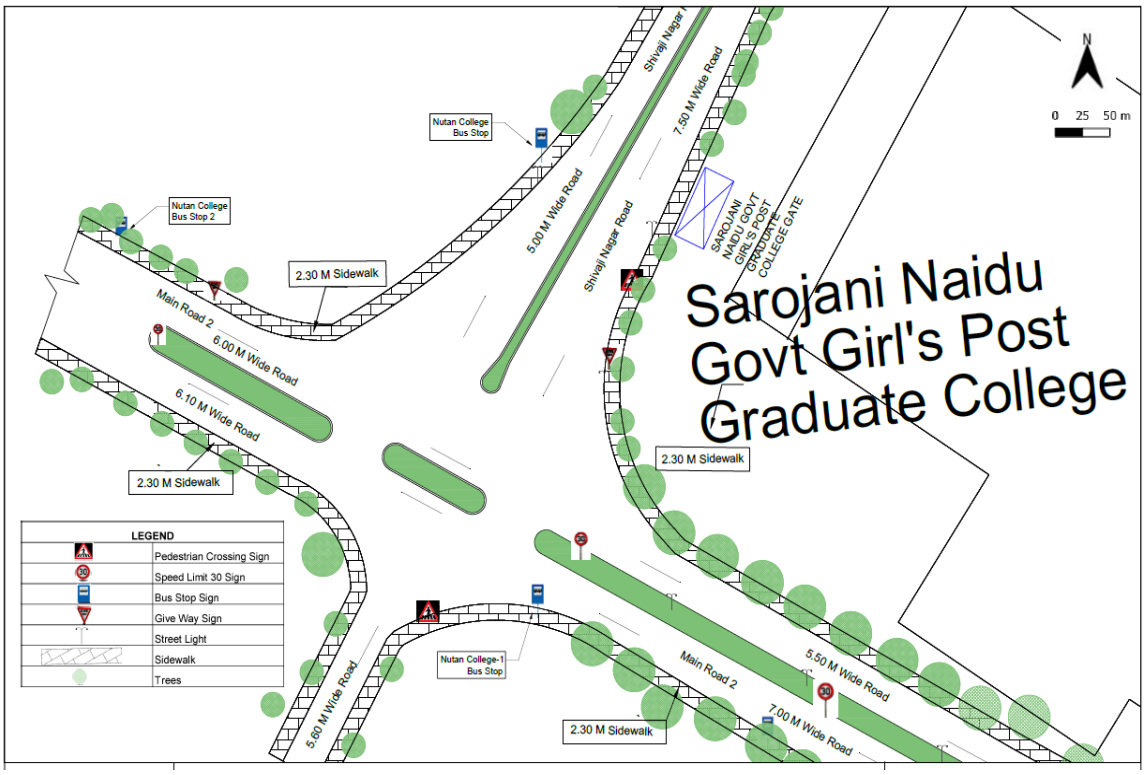


Figure 72. Details of location A (Existing) (Author)

The existing road network at this location comprises carriageways ranging from approximately 5.0 m to 7.0 m in width with curved turning geometries and channelizing

islands influencing vehicular circulation patterns. Although sidewalks of approximately 2.30 m width are available along selected stretches, pedestrian movement remains fragmented due to inadequate crossing infrastructure and absence of clearly defined pedestrian priority zones.

The presence of multiple bus stops near the junction further increases pedestrian activity and crossing demand. However, the existing condition lacks safe and designated pedestrian crossing facilities, forcing pedestrians and students to cross roads at uncontrolled locations. Continuous vehicular movement and irregular turning behaviour at the junction reduce pedestrian safety and visibility within the intersection area.

The location also lacks adequate school zone traffic calming measures. Vehicular speeds remain relatively high despite the presence of institutional activities and heavy pedestrian movement. Although certain traffic control elements such as speed limit signs, give-way signs, and pedestrian crossing signs are present, the overall junction environment remains predominantly vehicle-oriented.

The analysis of the existing condition highlights major issues related to pedestrian safety, accessibility, traffic conflict, and junction management. The location therefore requires comprehensive intervention measures focused on safer crossing infrastructure, traffic calming, improved pedestrian continuity, and organized circulation management.

7.4.2. Location A - Proposed Intervention

The proposed intervention at Location A focuses on improving pedestrian safety and regulating vehicular movement through the implementation of school zone traffic calming measures and pedestrian-oriented street design strategies (as shown in figure 73). The proposal aims to reduce traffic conflicts and create a safer and more organized junction environment suitable for institutional activities.

The design introduces designated pedestrian crossings at major pedestrian desire lines in accordance with IRC SP:32 guidelines for school zone planning and traffic safety. These crossings have been strategically located near institutional access points, bus stops, and junction approaches to facilitate safer pedestrian movement and improve crossing visibility within the corridor.

Traffic calming measures including rumble strips, stop lines, school ahead warning signs, reduced speed limit signage, and controlled intersection markings have been integrated to regulate vehicular speed and improve driver awareness near educational institutions. The proposed speed management measures contribute toward creating a safer traffic environment appropriate for pedestrian-intensive school zones.

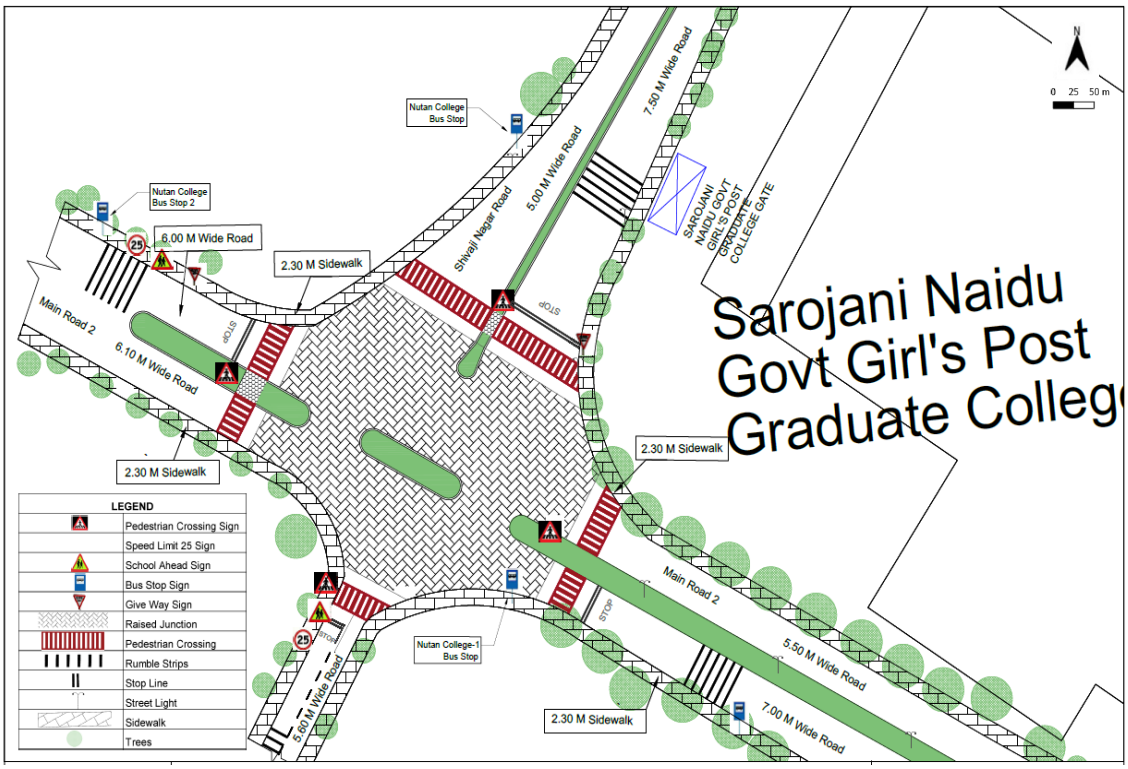


Figure 73. Details of location A (Proposed) (Author)

Textured pavement treatment has also been introduced within the junction area to enhance visual identification of the school zone and psychologically encourage lower vehicular speeds. Streetscape enhancement through landscape elements and plantation buffers further improves environmental quality and visual character within the junction environment.

The proposed intervention transforms the junction into a safer and more organized school zone by prioritizing pedestrian movement, improving crossing safety, and implementing effective traffic calming measures suitable for educational precincts.

7.4.3. Location B - Existing Condition

Location B represents an important junction node situated near Subhash Government Higher Secondary School and adjoining institutional areas (as shown in figure 74). The junction accommodates continuous vehicular circulation and significant pedestrian activity due to the presence of institutional access roads, bus stops, and pedestrian movement corridors.

The existing road network consists of carriageways ranging from approximately 6.0 m to 10.0 m in width accommodating mixed traffic movement including private vehicles, public transport, and pedestrian circulation. The irregular geometry of the junction and multiple turning movements contribute toward operational conflicts and reduced pedestrian safety.

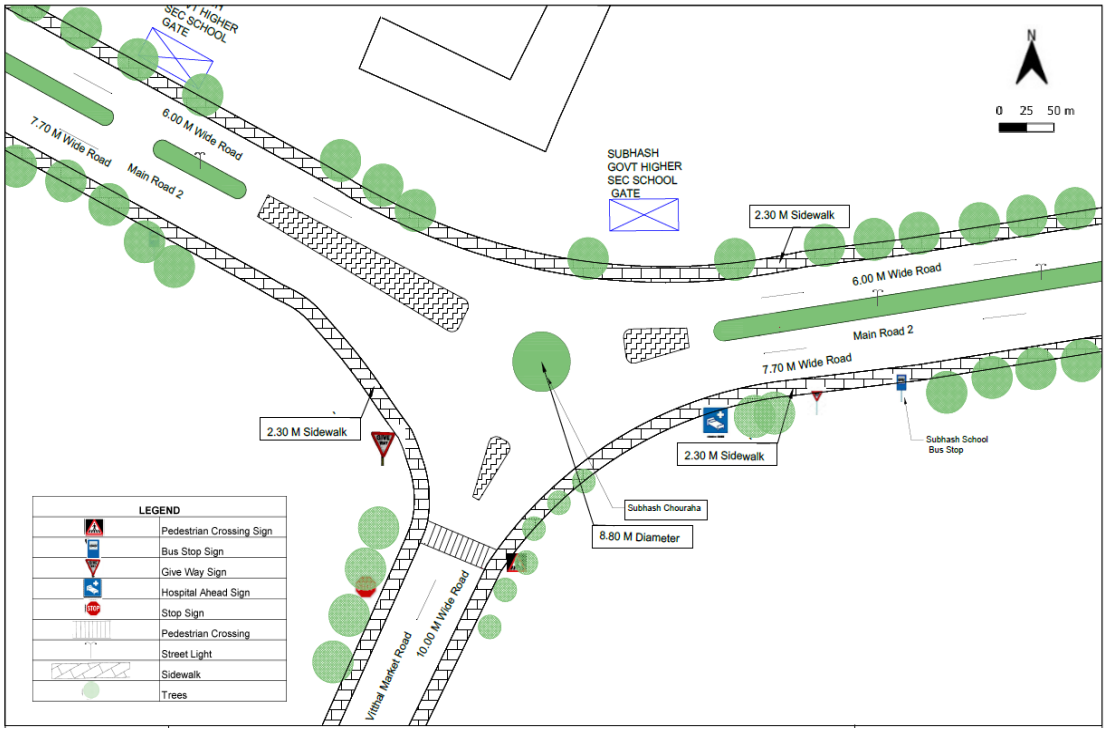


Figure 74. Details of location B (Existing) (Author)

Although sidewalks are available along portions of the corridor, pedestrian infrastructure remains insufficient in addressing the high pedestrian demand generated by nearby educational institutions and bus stop activities. Frequent uncontrolled road crossing behaviour is observed within the junction area due to inadequate crossing facilities and absence of clearly defined pedestrian priority zones.

The existing condition also reveals limited traffic calming measures and inadequate school zone treatments. Vehicular movement at relatively high speeds along the corridor creates unsafe conditions for students and pedestrians accessing schools and public transport facilities. Existing traffic control elements provide only limited regulation and do not sufficiently improve pedestrian safety within the junction area.

The location therefore requires comprehensive interventions focused on pedestrian safety enhancement, traffic calming, organized circulation management, and improved junction accessibility.

7.4.4. Location B - Proposed Intervention

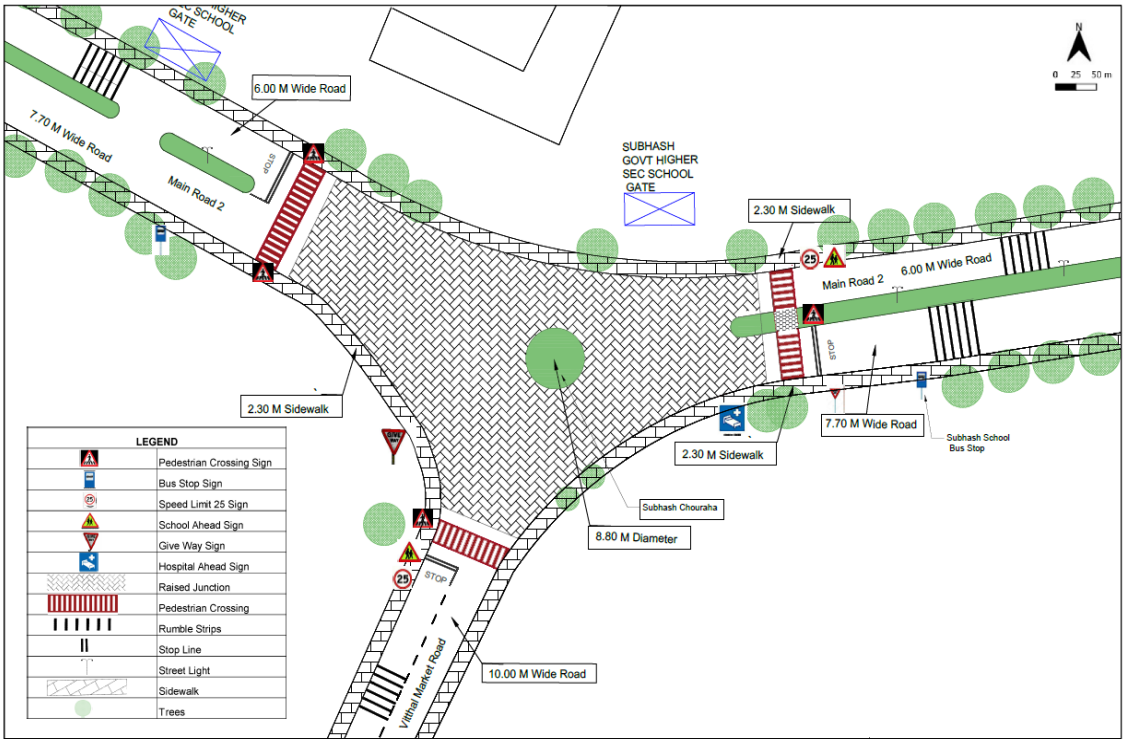


Figure 75. Details of location B (Proposed) (Author)

The proposed intervention for Location B focuses on improving junction safety, pedestrian accessibility, and traffic management through pedestrian-oriented design and traffic calming measures (as shown in figure 75). The proposal aims to regulate vehicular movement while strengthening pedestrian connectivity between institutional areas, bus stops, and adjoining corridors.

The redesigned junction incorporates designated pedestrian crossings strategically located near institutional access points and pedestrian desire lines. High-

visibility pavement markings improve pedestrian priority and strengthen driver awareness within the school zone environment.

Textured paving treatment has been introduced within the junction area to visually define the school zone and encourage lower vehicular speeds through psychological traffic calming. Additional interventions including rumble strips, stop lines, school ahead signage, and reduced speed limit signs further contribute toward safer traffic operations near educational institutions.

The proposed intervention improves pedestrian safety, reduces traffic conflicts, and enhances the overall functionality and organization of the junction during peak institutional activity hours.

7.4.5. Location C - Existing Condition

Location C represents an important school access corridor situated adjacent to Kendriya Vidyalaya No. 02 within the study area (as shown in figure 76). The corridor experiences significant pedestrian activity during school arrival and dispersal hours due to continuous student movement along the roadway and surrounding institutional activities.

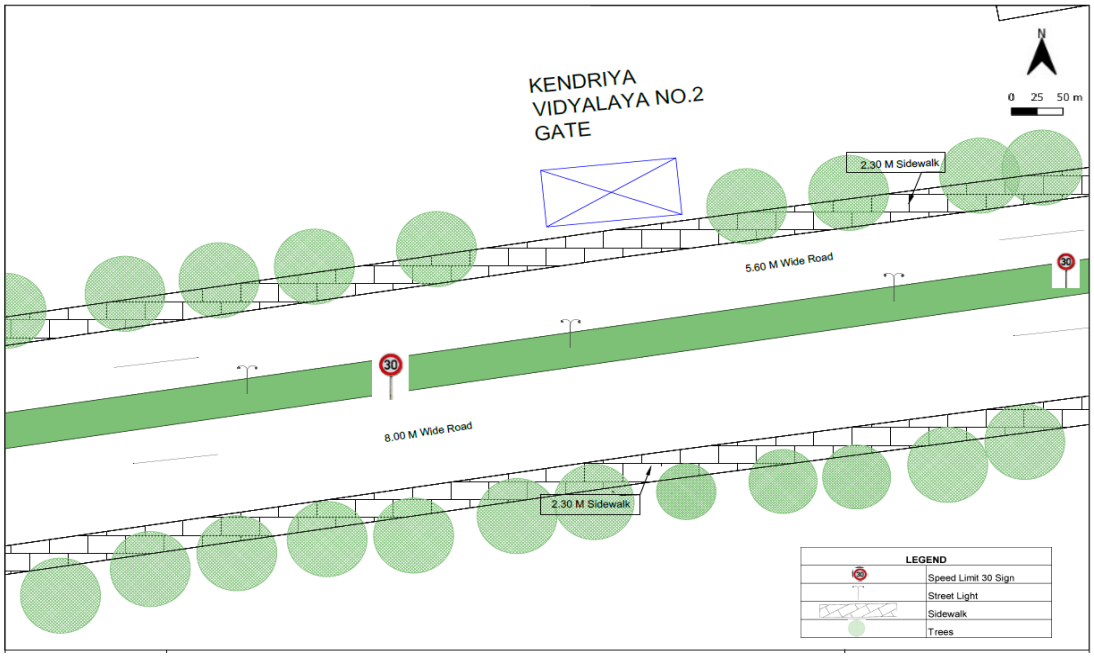


Figure 76. Details of location C (Existing) (Author)

The existing road section consists of an approximately 8.0 m wide carriageway with sidewalks of nearly 2.30 m width provided along both sides of the corridor. The roadway accommodates mixed vehicular traffic while simultaneously functioning as a major pedestrian access route for students and institutional users.

Although pedestrian sidewalks are available, the existing condition lacks adequate school zone treatments and designated pedestrian crossing infrastructure near the school gate. Students and pedestrians are often required to cross the roadway without controlled crossing facilities, resulting in potential safety risks and pedestrian-vehicle conflicts during peak activity periods.

Vehicular movement along the corridor occurs at relatively higher operating speeds despite the presence of educational institutions and substantial pedestrian activity. The absence of traffic calming measures and speed management infrastructure further reduces pedestrian safety within the corridor.

The analysis of Location C identifies the need for interventions focused on pedestrian safety enhancement, speed regulation, improved crossing facilities, and stronger school zone identification measures to create a safer and more accessible movement corridor.

7.4.6. Location C - Proposed Intervention

The proposed intervention for Location C focuses on improving pedestrian safety and establishing an effective school zone treatment along the corridor adjacent to Kendriya Vidyalaya No. 02 (as shown in figure 77). The proposal aims to create a safer crossing environment for students through the introduction of pedestrian-oriented traffic calming measures and enhanced school zone visibility.

A designated raised pedestrian crossing has been proposed near the school gate to facilitate safe and convenient pedestrian movement across the roadway. The raised pedestrian crossing improves driver visibility of pedestrians and encourages vehicles to reduce speed within the school zone environment. The crossing has been strategically located along the primary pedestrian desire line connecting both sides of the corridor and strengthening pedestrian priority near the institutional entrance.

Additional traffic calming measures including rumble strips, stop lines, pedestrian crossing signage, and school zone warning elements have been introduced to improve driver awareness and regulate vehicular movement within the corridor. These interventions contribute toward safer traffic operations and reduced pedestrian-vehicle conflicts near the school access point.

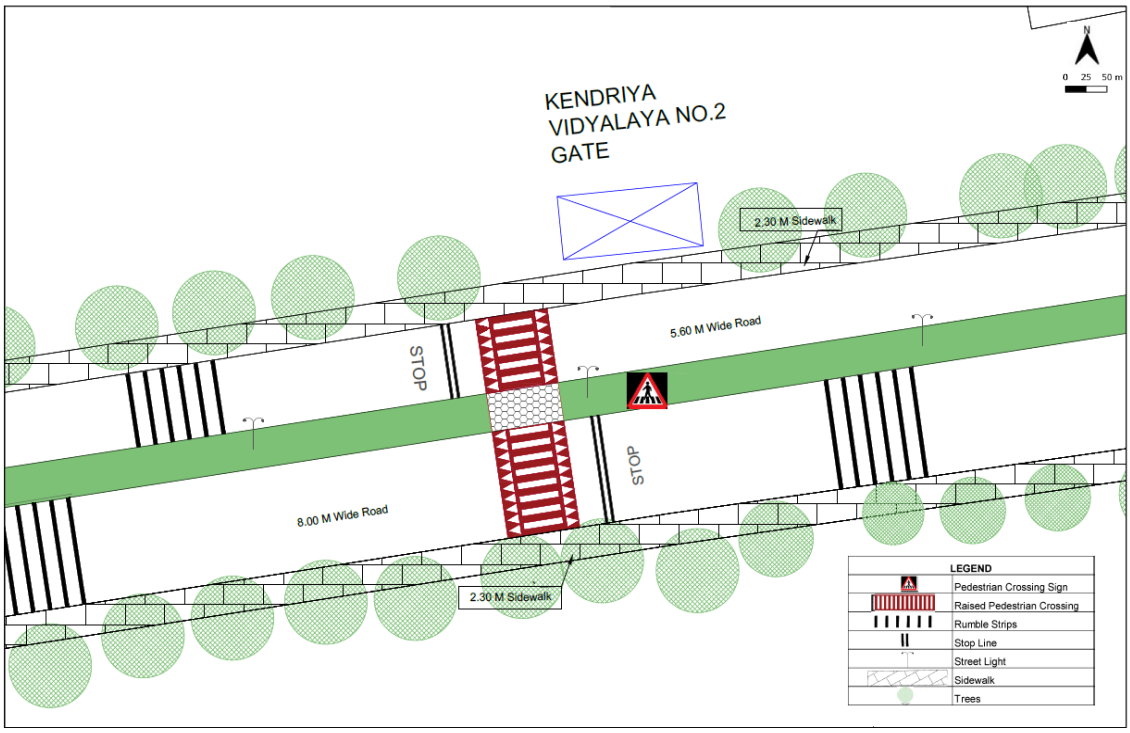


Figure 77. Details of location C (Proposed) (Author)

The proposal retains the existing sidewalk network along both sides of the road to ensure continuity in pedestrian movement and accessibility.

The intervention adopts school zone planning principles recommended under IRC SP:32 by prioritizing pedestrian safety and implementing effective speed management strategies suitable for educational areas. The proposed measures are expected to improve crossing safety for students, strengthen pedestrian visibility, reduce vehicular speed, and create a safer and more organized school access corridor.

7.4.7. Location D - Existing Condition

Location D represents a major rotary junction within the study area accommodating traffic movement from multiple connecting roads of varying widths (as shown in figure 78). The junction functions as an important circulation node for both

local and through traffic while also serving nearby institutional and pedestrian movement requirements.

The existing rotary has an approximate diameter of 15.30 m and is connected to carriageways ranging from 4.5 m to 9.1 m in width. Although the junction geometry facilitates continuous vehicular circulation, the absence of adequate pedestrian priority measures reduces pedestrian safety and accessibility at the intersection approaches

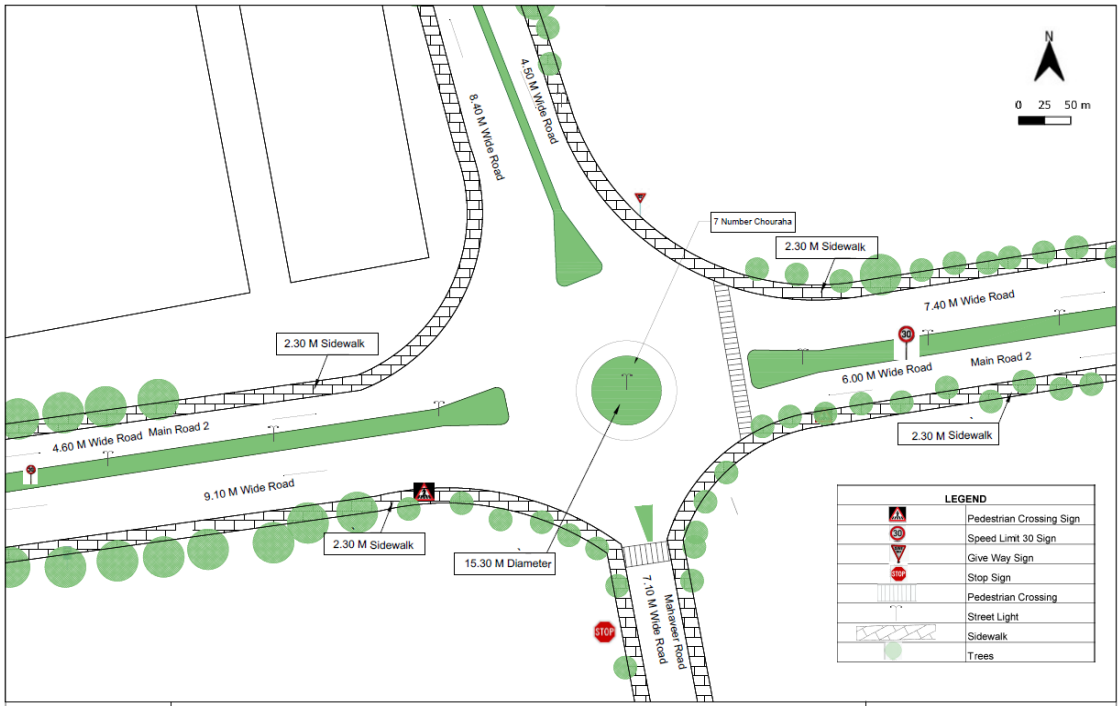


Figure 78. Details of location D (Existing) (Author)

Sidewalks are present along adjoining roads, however, pedestrian crossing facilities remain limited and discontinuous near the rotary. The existing condition lacks integrated school zone treatments and traffic calming measures despite the presence of considerable pedestrian activity within the surrounding corridor network.

Basic traffic control elements including stop signs, give-way signs, pedestrian crossing markings, and speed limit signage are present at selected approaches. However, high vehicular turning movements and insufficient pedestrian protection measures continue to create unsafe crossing conditions and reduced pedestrian comfort. The overall design remains vehicle-oriented and requires intervention measures focused on pedestrian safety, traffic calming, and circulation organization.

The analysis of Location D highlights the need for enhanced pedestrian crossing infrastructure, improved traffic regulation, and junction redesign to create a safer and more efficient movement environment for all road users.

7.4.8. Location D - Proposed Intervention

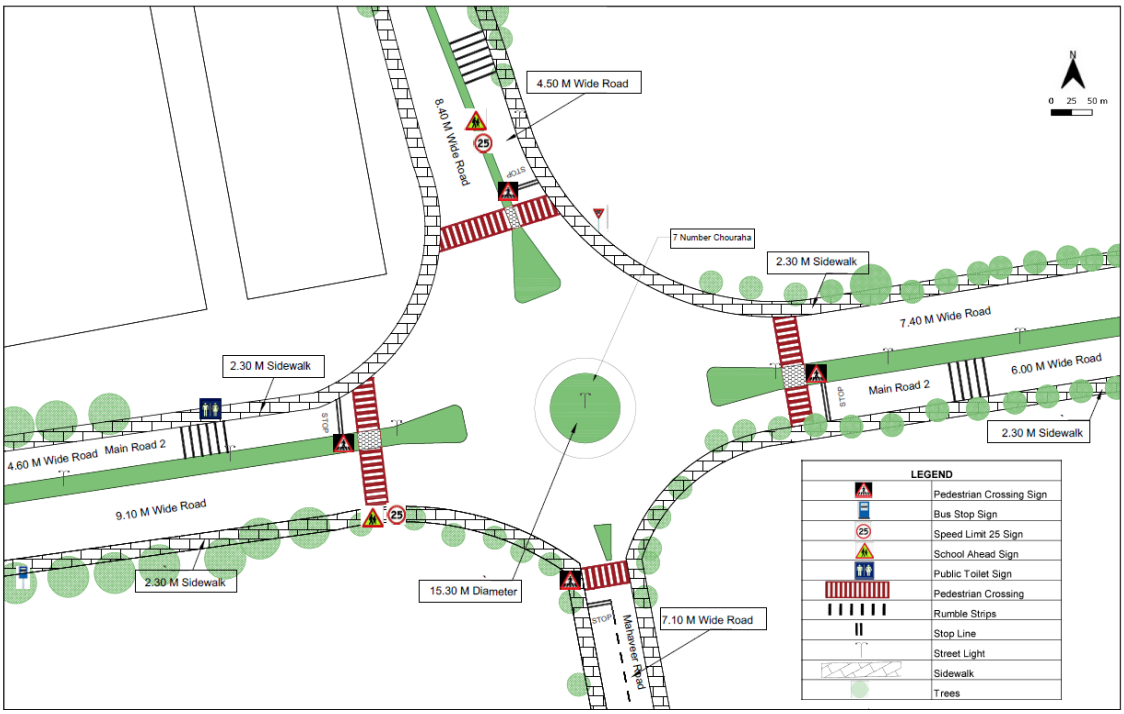


Figure 79. Details of location D (Proposed) (Author)

The proposed intervention at Location D focuses on improving pedestrian safety, regulating vehicular movement, and enhancing the operational efficiency of the rotary junction through the introduction of school zone traffic calming measures and pedestrian-oriented design interventions (as shown in figure 79).

The redesigned rotary incorporates designated pedestrian crossings at all major junction approaches to facilitate safe pedestrian movement across the roadway. These crossings are strategically positioned along pedestrian desire lines and key movement corridors to improve accessibility and reduce uncontrolled crossing behaviour within the intersection area.

Traffic calming measures including rumble strips, stop lines, reduced speed limit signage, and school ahead warning signs have been integrated at the rotary approaches to encourage lower vehicular speeds and improve traffic discipline near the institutional

zone. These interventions help reduce traffic conflicts while improving pedestrian safety at entry and exit points of the junction.

The proposal further improves junction visibility and spatial organization through clearly defined traffic control measures and pedestrian infrastructure. The intervention adopts school zone planning principles by prioritizing vulnerable road users and creating a safer, traffic-calmed, and pedestrian-friendly urban environment.

The proposed design is expected to improve pedestrian safety, regulate vehicular speed, streamline circulation efficiency, and enhance the overall operational functionality of the rotary junction during peak institutional activity hours.

7.4.9. Location E - Existing Condition

The existing condition at Location E represents a corridor segment accommodating pedestrian movement and public transport activity within the school zone area. The location includes an existing bus stop facility serving daily commuters, students, and institutional users travelling through the corridor (as shown in figure 80).

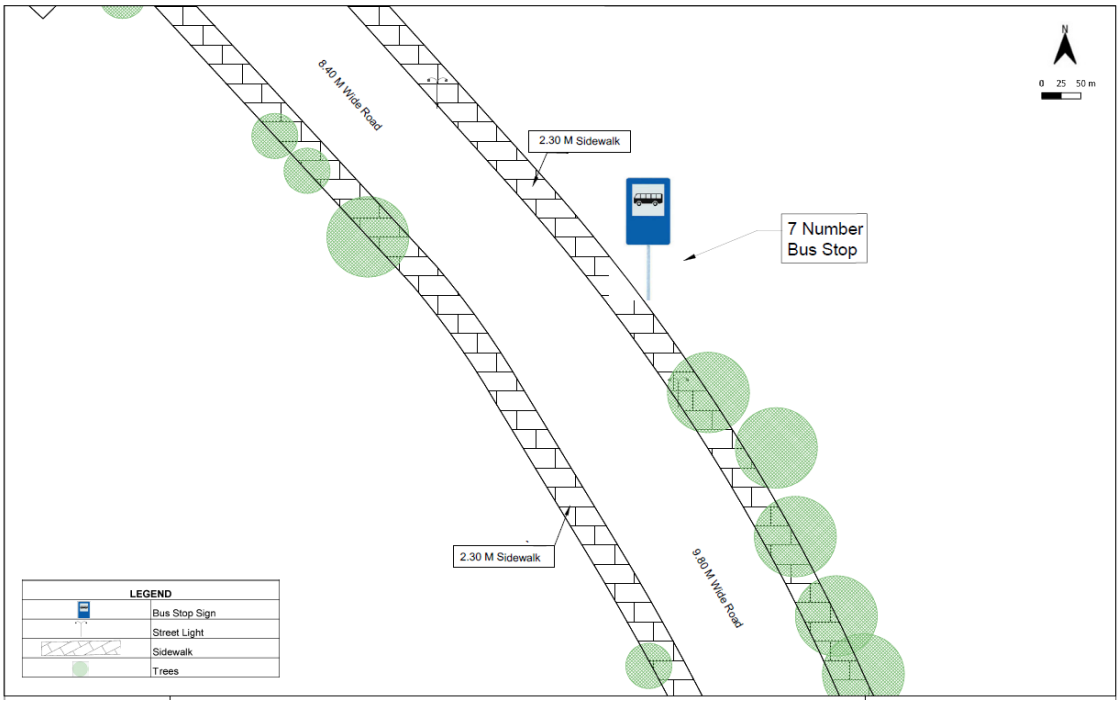


Figure 80. Details of location E (Existing) (Author)

The road section consists of an approximately 9.80 m wide carriageway with sidewalks of nearly 2.30 m width provided along both sides of the corridor. The existing

sidewalks facilitate pedestrian movement; however, the overall corridor remains primarily vehicle-oriented with limited school zone safety treatments and pedestrian-priority measures.

The location experiences regular pedestrian activity due to the presence of the bus stop and surrounding institutional land uses. Although basic pedestrian infrastructure and street lighting are available, the corridor lacks designated pedestrian crossing facilities and traffic calming measures required to ensure safer pedestrian movement near the public transport access point.

The analysis of the existing condition highlights the need for improved pedestrian safety measures, enhanced public transport integration, and traffic calming interventions to create a safer and more accessible school zone corridor environment.

7.4.10. Location E - Proposed Intervention

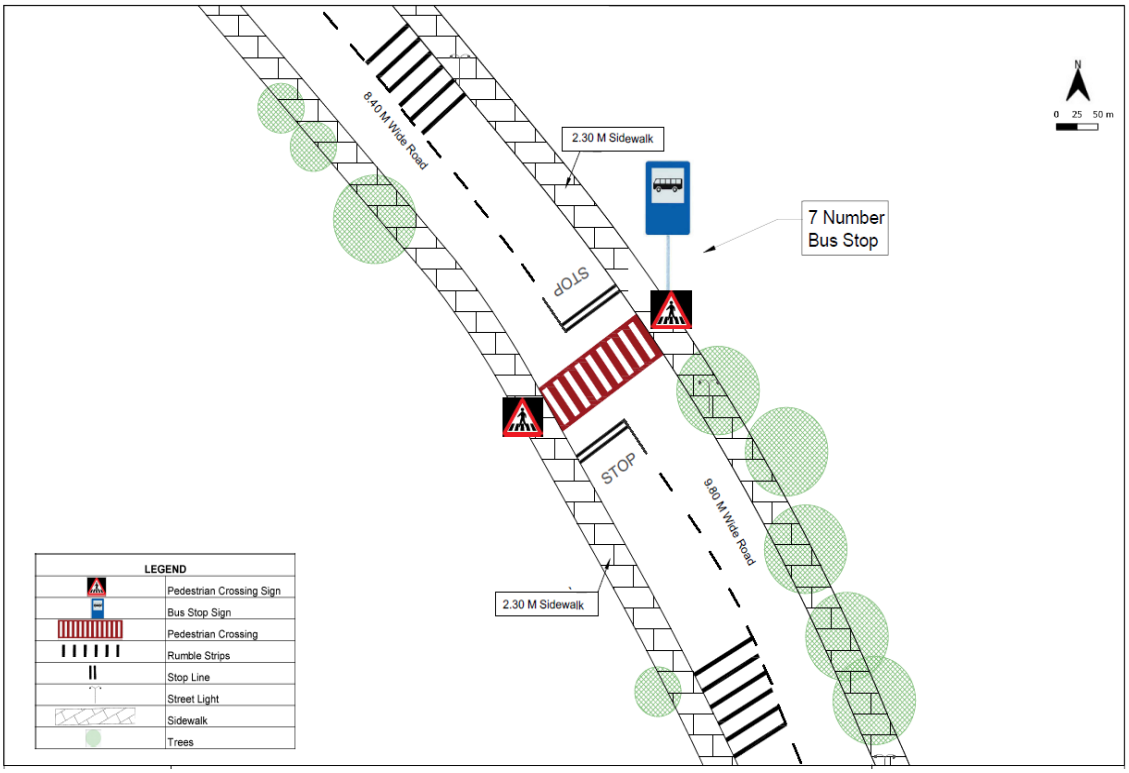


Figure 81. Details of location E (Proposed) (Author)

The proposed intervention at Location E also includes the provision of a designated pedestrian crossing near the bus stop to facilitate safer road crossing for students, pedestrians, and public transport users accessing the corridor (as shown in

figure 81). The crossing has been strategically located along the major pedestrian desire line connecting the bus stop and adjoining sidewalks.

The intervention improves pedestrian visibility and establishes safer crossing conditions by alerting drivers about pedestrian movement within the school zone. Additional traffic calming measures including rumble strips and stop lines have been incorporated to encourage vehicles to reduce speed before approaching the crossing zone.

The intervention adopts school zone planning principles by prioritizing pedestrian movement and implementing safety measures suitable for student-intensive activity areas. The proposed measures are expected to improve pedestrian safety near the bus stop, regulate vehicular speed, and enhance overall walkability and accessibility within the corridor.

7.4.11 Location F - Existing Condition



Figure 82. Details of location F (Existing) (Author)

The existing condition at Location F represents a junction area connecting Sarojini Naidu Road and Durga Mandir Road within the school zone corridor (as shown in figure 82). The location accommodates mixed vehicular movement through merging

road sections and functions as an important circulation node within the institutional precinct.

The existing road network comprises carriageways ranging from approximately 7.20 m to 10.00 m in width with channelizing islands provided to guide vehicular circulation at the junction. Sidewalks of nearly 2.30 m width are available along the road edges, facilitating pedestrian movement within the corridor.

The junction geometry and merging traffic movement create potential conflict points between vehicles and pedestrians, particularly during peak institutional activity hours. Although pedestrian infrastructure and basic elements are present, the location lacks designated pedestrian crossing facilities and school zone traffic calming measures required for safer pedestrian movement.

Landscape elements and channelizing islands assist in organizing vehicular circulation; however, the overall junction environment remains primarily vehicle-oriented with limited pedestrian-priority treatments.

The absence of pedestrian crossings, speed management measures, and organized school zone safety infrastructure reduces pedestrian safety and accessibility within the junction area. The analysis of the existing condition therefore highlights the need for improved pedestrian infrastructure, traffic calming measures, and enhanced junction organization to create a safer and more accessible school zone environment.

7.4.12 Location F - Proposed Intervention

The proposed intervention at Location F focuses on improving pedestrian safety and regulating vehicular movement at the junction through the implementation of school zone traffic calming measures and pedestrian-oriented street design strategies (as shown in figure 83). The proposal aims to create a safer and more organized movement environment within the institutional corridor by reducing vehicular speed and strengthening pedestrian priority at critical crossing points.

The design incorporates designated pedestrian crossings at all major junction approaches to facilitate safe pedestrian movement across the roadway. These crossings

are strategically located along pedestrian desire lines and near conflict points to improve accessibility and reduce unsafe crossing behaviour.

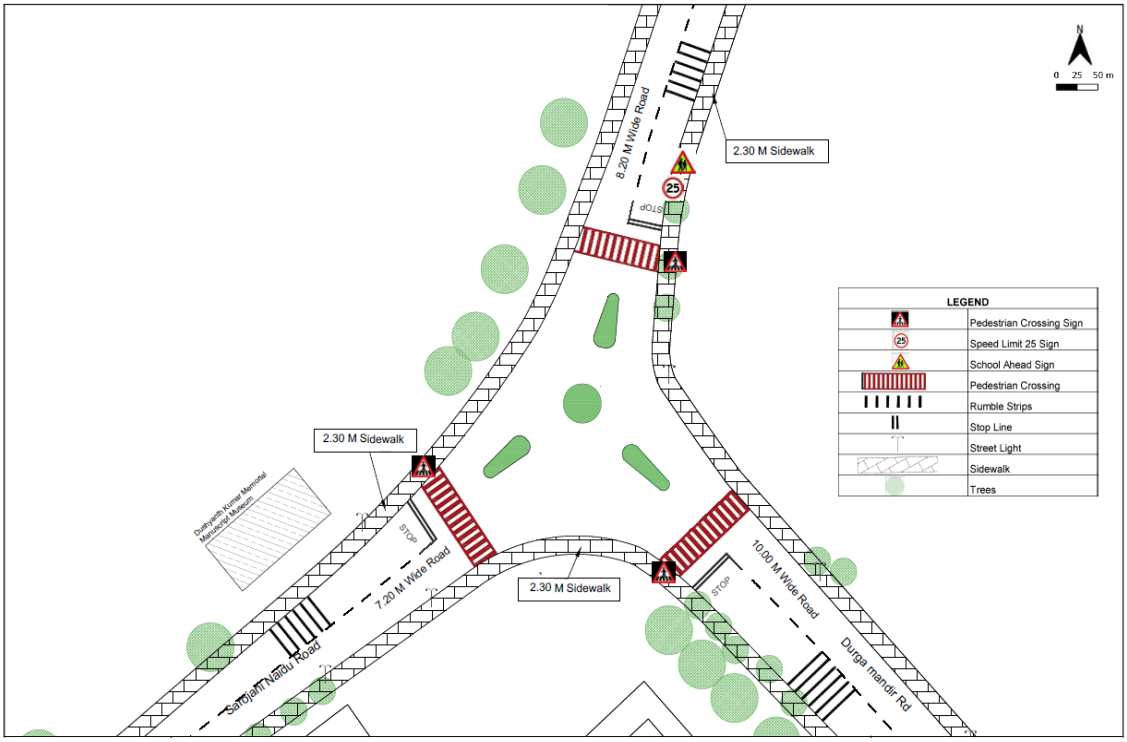


Figure 83. Details of location F (Proposed) (Author)

Traffic calming measures including rumble strips, stop lines, reduced speed limit signage, and school ahead warning signs have been introduced to encourage vehicles to reduce speed before approaching the intersection. These interventions help in minimizing pedestrian-vehicle conflicts and contribute toward safer traffic operations within the school zone.

Continuous sidewalks of approximately 2.30 m width have been maintained along all road edges to improve pedestrian continuity and accessibility. Existing landscape elements and channelizing islands have been integrated within the proposal to streamline vehicular circulation, improve junction legibility, and enhance the visual quality of the street.

The proposed design adopts school zone planning principles by prioritizing vulnerable road users and introducing effective speed management strategies suitable for educational precincts. The intervention is expected to improve pedestrian safety, enhance

driver awareness, reduce vehicular speed, and create a safer and more pedestrian-friendly junction environment.

7.4.13. Location G - Existing Condition

The existing condition at Location G represents an important junction area surrounding Sarojini Naidu Government Girls Post Graduate College within the institutional corridor (as shown in figure 84). The junction accommodates mixed vehicular movement and functions as a significant access node connecting Sarojini Naidu Road, Shivaji Nagar Road, and Machala Colony Road.

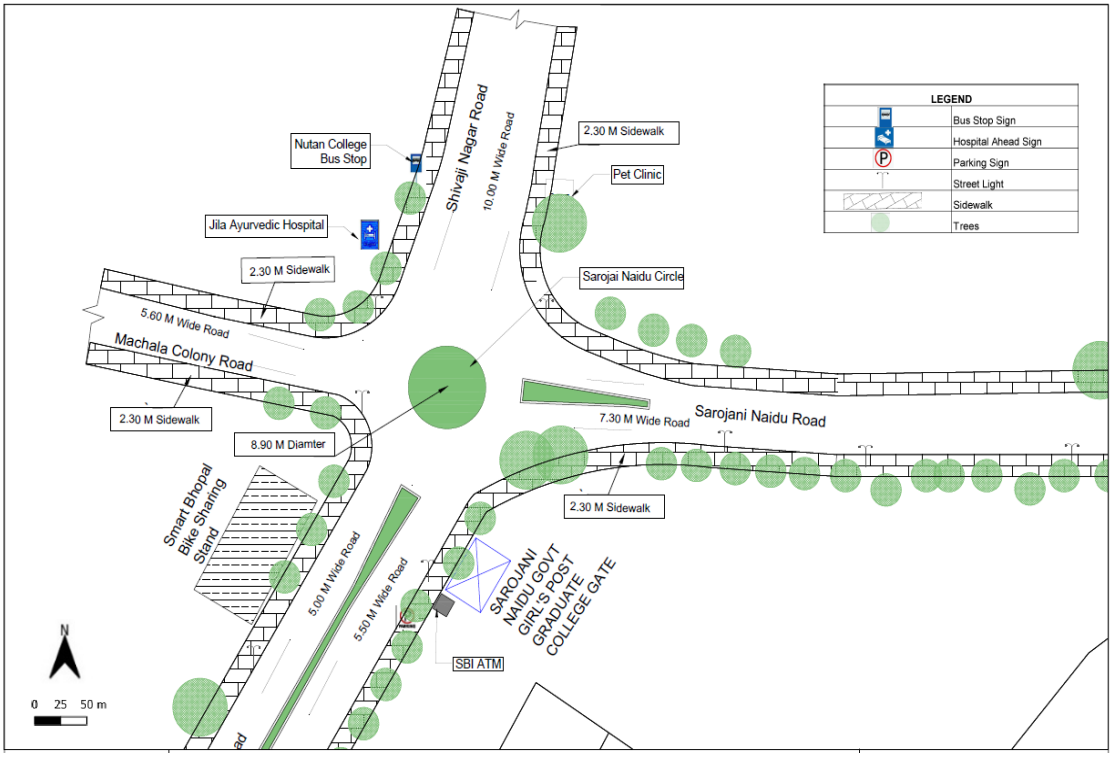


Figure 84. Details of location G (Existing) (Author)

The existing road network comprises carriageways ranging from approximately 5.50 m to 10.00 m in width with a central rotary island and channelizing elements influencing vehicular circulation within the junction area. Sidewalks of nearly 2.30 m width are available along most road edges, facilitating pedestrian movement within the corridor.

The location experiences considerable pedestrian and vehicular activity due to the presence of nearby institutional, commercial, and public facilities including the college

entrance, bus stop, hospital, ATM, and surrounding activity areas. Although basic pedestrian infrastructure and public amenities are present, the junction environment remains largely vehicle-oriented with limited pedestrian-priority measures.

Existing landscape elements, avenue plantation, and street lighting infrastructure contribute toward the visual character and environmental quality of the corridor. The central rotary and channelizing islands assist in organizing vehicular movement; however, the absence of designated pedestrian crossings and traffic calming measures reduces pedestrian safety within the junction area.

The existing condition also reveals insufficient school zone treatments and limited traffic regulation despite the high pedestrian concentration generated by institutional activities and public transport movement. The lack of organized pedestrian crossing infrastructure creates potential pedestrian-vehicle conflict points near major movement corridors and activity nodes.

The analysis of the existing condition therefore highlights the need for improved pedestrian safety measures, enhanced traffic organization, better public transport integration, and comprehensive school zone interventions to create a safer and more accessible institutional junction environment.

7.4.14. Location G - Proposed Intervention

Location G represents a major institutional junction surrounding Sarojini Naidu Government Girls Post Graduate College and adjoining public activity areas (as shown in figure 85). The proposed intervention focuses on improving pedestrian safety, traffic regulation, junction organization, and streetscape quality through comprehensive school zone planning measures.

The proposal introduces designated pedestrian crossings at all major approaches to facilitate safe pedestrian movement across the roadway. These crossings have been strategically located near institutional access points, bus stops, and pedestrian desire lines to reduce unsafe crossing behaviour and improve pedestrian connectivity within the junction area.

Traffic calming measures including rumble strips, stop lines, reduced speed limit signage, and school ahead warning signs have been integrated at junction approaches to regulate vehicular movement and improve driver awareness within the school zone. These interventions help reduce pedestrian-vehicle conflicts and strengthen operational safety around the institutional precinct.

Continuous sidewalks have been maintained along all road edges to improve pedestrian continuity and accessibility.

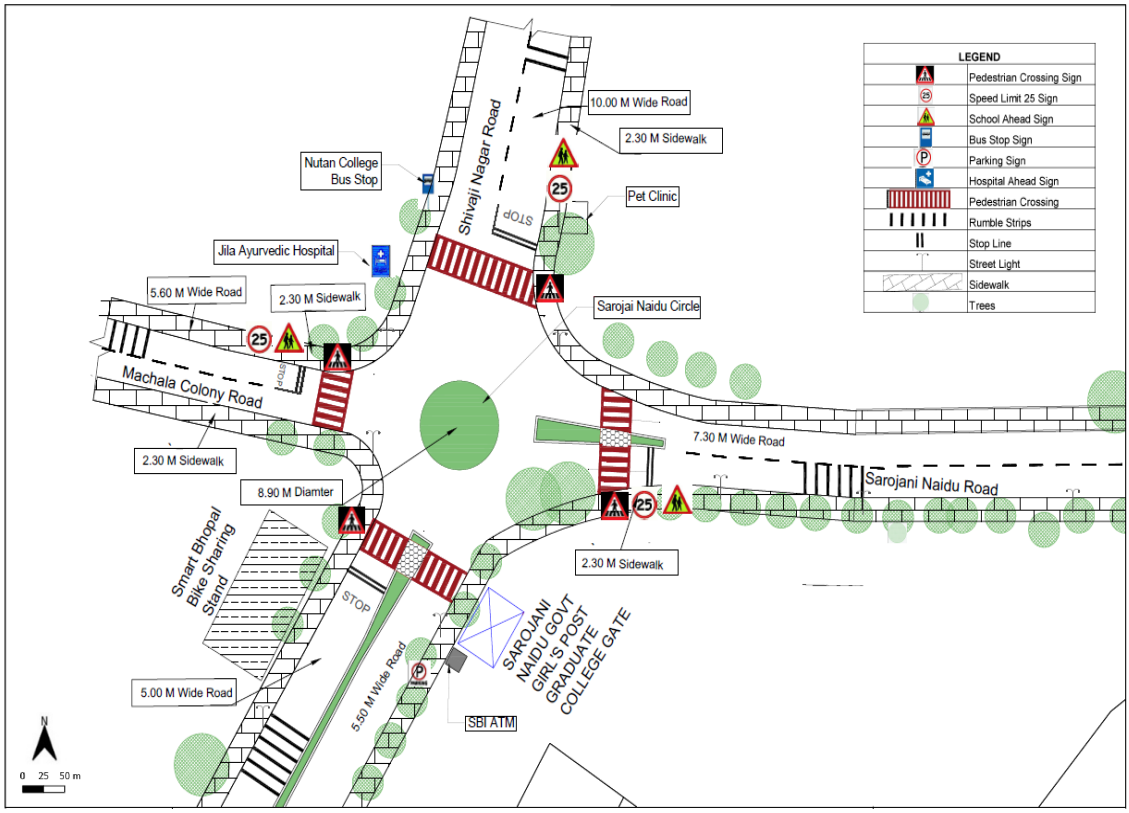


Figure 85. Details of location G (Proposed) (Author)

The intervention adopts pedestrian-oriented and child-friendly planning principles aimed at improving accessibility, enhancing pedestrian safety, reducing vehicular speed, and creating a safer and more organized institutional streetscape environment.

7.5. Overall Proposal Summary

The proposed school zone improvement plan adopts a comprehensive and pedestrian-oriented planning approach aimed at enhancing safety, accessibility, mobility,

and streets quality within the institutional vicinity. The proposal has been developed based on detailed analysis of existing traffic conditions, pedestrian movement patterns, safety concerns, and conflict zones identified during field surveys and spatial assessment of the study area (as shown in figure 86).

The overall intervention strategy prioritizes pedestrian safety through the introduction of school zone traffic calming measures and improved pedestrian infrastructure in accordance with IRC SP:32 guidelines. Major interventions proposed within the study area include designated pedestrian crossings, raised pedestrian crossings, rumble strips, stop lines, reduced speed limit signage, school ahead warning signs, continuous sidewalks, junction redesign, and streetscape enhancement measures.

The proposal also incorporates organized circulation systems, rotary improvements, channelizing islands, bus stop integration, avenue plantation, and street lighting infrastructure to improve operational efficiency, accessibility, environmental quality, and visual character within the school zone.

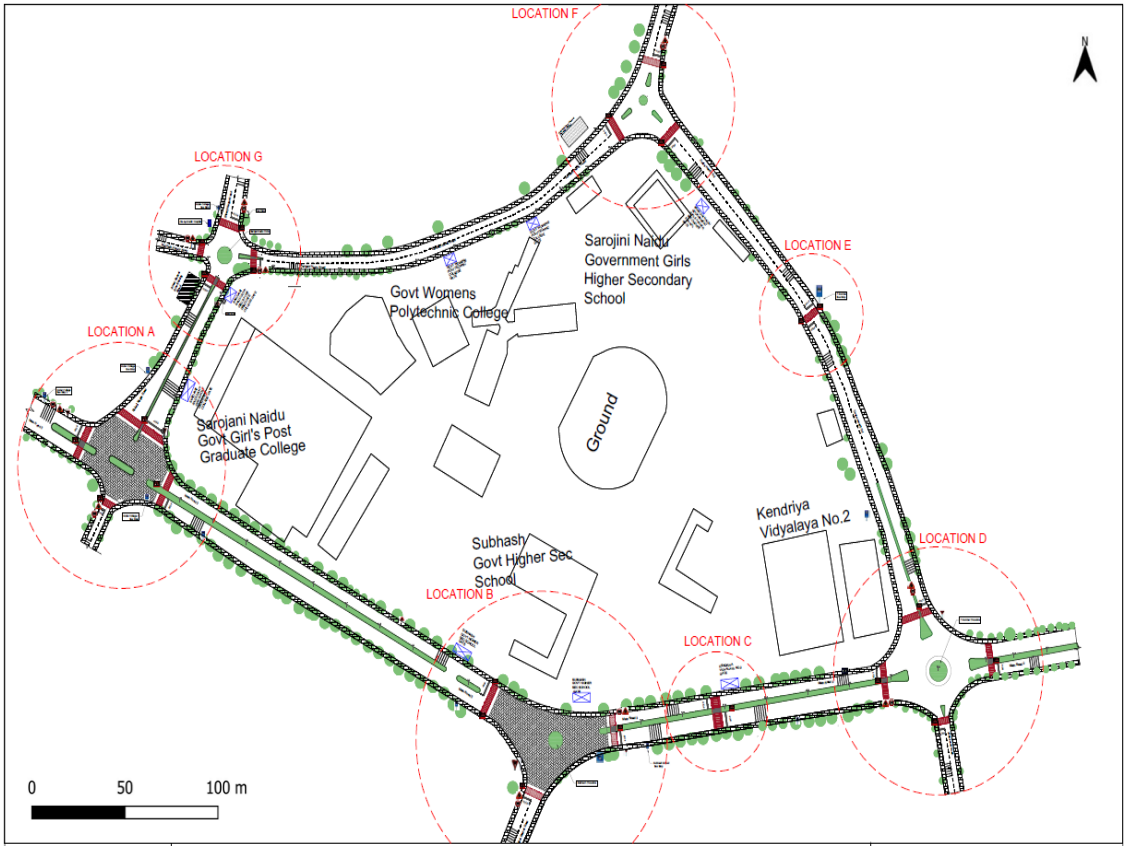


Figure 86. Proposed plan of school zone (Author)

The proposed interventions collectively aim to reduce vehicular speed, improve pedestrian visibility, strengthen driver awareness, minimize pedestrian-vehicle conflicts, and create a safer and more accessible institutional environment for students and other vulnerable road users.

The proposal adopts complete street and child-friendly planning principles by balancing the movement needs of pedestrians, students, public transport users, and vehicular traffic. Overall, the proposed school zone improvement strategy is expected to significantly improve road safety, strengthen walkability, enhance accessibility, and improve the overall urban quality and functionality of the institutional corridor.

CHAPTER 8

CONCLUSION

This study explored school zone safety from the perspective of urban planning, transportation planning, infrastructure design, behavioural factors, and policy implementation. Through literature review, spatial analysis, field investigations, and safety assessments, the study examined the challenges faced by children while commuting to and from educational institutions and proposed suitable interventions for improving the overall safety and quality of the school zone environment.

8.1. Achievement of Research Objectives

The study successfully achieved the objectives established during the research design phase. A detailed understanding of school zone safety was developed through the review of Indian and international literature, IRC guidelines, and global safety frameworks. The literature review highlighted that effective school zone planning requires the integration of engineering, education, enforcement, evaluation, and community participation.

The study further identified the major parameters influencing school zone safety, including pedestrian infrastructure, traffic behaviour, road geometry, traffic calming measures, signage, enforcement systems, and stakeholder involvement. Comparative analysis between Indian and global practices revealed that although India possesses technical guidelines related to school safety, implementation and enforcement remain inadequate compared to global child-centred planning approaches.

GIS-based spatial analysis was successfully used to identify areas with high school density and accident-prone conditions within Bhopal city. Shivaji Nagar was selected as the study area due to its concentration of educational institutions, high pedestrian activity, and traffic-related safety concerns. The integration of GIS mapping with accident data and land use characteristics proved effective in identifying school zones requiring immediate intervention.

Field surveys, traffic observations, and pedestrian assessments provided detailed insights into the existing mobility and safety conditions within the study area. These assessments helped in identifying critical infrastructural deficiencies, unsafe pedestrian

behaviour, congestion patterns, and operational challenges affecting school children and other road users.

8.2. Major Findings of the Study

The study revealed several critical safety concerns within the selected school zone area. One of the major findings was the inadequate condition of pedestrian infrastructure. Many stretches lacked continuous sidewalks, while several existing footpaths were obstructed by encroachments, vegetation, garbage, or parked vehicles. Due to the absence of safe pedestrian facilities, students were frequently observed walking directly on the carriageway, thereby increasing the risk of pedestrian-vehicular conflicts.

The analysis also revealed that congestion during school opening and closing hours significantly affected traffic movement and pedestrian safety. Informal parking activities, roadside school bus stoppages, and unmanaged pick-up and drop-off activities created operational inefficiencies within the road network. Several junctions and crossings lacked organized pedestrian facilities, forcing children to cross roads in unsafe conditions.

Survey findings indicated that a large number of students and teachers perceived the school zone as unsafe. Concerns related to speeding vehicles, unsafe crossings, inadequate footpaths, and traffic congestion were repeatedly highlighted during the surveys. The pedestrian volume analysis further demonstrated high pedestrian concentration during peak school hours, confirming the need for dedicated pedestrian infrastructure and traffic management interventions.

The research also highlighted the gap between existing guidelines and ground-level implementation. Although IRC guidelines provide recommendations regarding sidewalks, signage, traffic calming, and pedestrian crossings, many of these provisions were absent or poorly maintained within the study area.

8.3. Proposed Planning and Safety Interventions

Based on the identified issues and field analysis, the study proposed a series of children-inclusive planning and safety interventions aimed at improving the overall functionality and safety of the school zone environment. The proposed interventions

focused primarily on strengthening pedestrian infrastructure, improving junction organization, and enhancing traffic management systems.

The proposals included the provision of continuous and obstruction-free sidewalks, designated pedestrian crossings, raised crossings, traffic calming measures, improved signage and road markings.

Special emphasis was placed on reducing pedestrian-vehicular conflict points and improving the visibility and safety of children within the road environment. The proposals were developed in accordance with IRC guidelines and global best practices related to child-friendly and pedestrian-oriented urban design.

8.4. Significance of Children-Inclusive Planning

The study establishes that children-inclusive planning is an essential component of sustainable and equitable urban development. School zones should not merely function as vehicular corridors but must be designed as safe public spaces prioritizing the needs of children and pedestrians. Safe and accessible school environments encourage walking and active mobility while reducing dependency on private vehicles and minimizing traffic congestion.

The research highlights that improving school zone safety contributes not only to transportation efficiency but also to broader social, environmental, and public health objectives. Safe school environments promote equitable access to education, particularly for children who rely on walking or public transport for daily travel. Therefore, integrating child-centred planning principles into urban policies and transportation systems is necessary for creating inclusive cities.

8.5. Conclusion

The study concludes that school zone safety is a critical urban planning concern requiring immediate attention within Indian cities. Existing conditions within many school zones expose children to significant safety risks due to inadequate pedestrian infrastructure, poor traffic management, weak enforcement, and increasing vehicular pressure. The findings demonstrate that child-friendly planning interventions can significantly improve pedestrian safety, accessibility, and mobility within school environments.

The proposed children-inclusive planning and safety interventions provide a framework for creating safer and more walkable school zones that prioritize vulnerable road users. The research emphasizes that achieving safer school environments requires an integrated approach involving infrastructure improvements, policy implementation, behavioural awareness, stakeholder coordination, and continuous monitoring.

Overall, the study reinforces the importance of integrating child-centred principles into urban planning and transportation policies to create inclusive, safe, and sustainable urban environments for present and future generations.

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ANNEXURE

Questionnaire for Students

1. Which class are you studying in?

   a) 1st
   b) 2nd
   c) 3rd
   d) 4th
   e) 5th
   f) 6th
   g) 7th
   h) 8th
   i) 9th
   j) 10th
   k) 11th
   l) 12^{th}
   m) Diploma

2. What is your age?

3. What is your Gender?

   a) Male
   b) Female
   c) Other

4. How do you commute to school?

   a) Walk
   b) Bicycle
   c) Bus
   d) Auto/Magic
   e) Bike
   f) Car

5. With whom do you travel while coming to school?

   a) Alone
   b) With friends
   c) With family
   d) With school staff

6. What makes you scared or uncomfortable?

   a) Fast vehicles

b) No place to walk
c) Too much traffic
d) Big vehicles
e) Another road user

7. How safe do you feel near your school in the following situations?

Situations	Very safe	Safe	Neutral	Unsafe	Very Unsafe
While walking on the footpath/sidewalk	☐	☐	☐	☐	☐
While walking on the road (no footpath available)	☐	☐	☐	☐	☐
While crossing the road near school	☐	☐	☐	☐	☐
Near parked vehicles or traffic congestion	☐	☐	☐	☐	☐
Near the school entrance gate	☐	☐	☐	☐	☐

8. How fast do vehicles usually travel near your school?

a) Very fast
b) Fast
c) Normal
d) Slow

9. Have you ever witnessed or experienced any minor or major accident in area around your school? If yes, share details in brief in last (other) option.

a) Yes
b) No

Questionnaire for Teachers

1. What is your Gender?

a) Male
b) Female
c) Other

2. Which age group do you belong?

a) 22-30
b) 30-40
c) 40-50
d) 50-60
e) >60

3. What is range of your monthly income?

a) 20,000-40,000
b) 40,000-60,000
c) 60,000-80,000
d) 80,000-1 lakhs
e) >1 lakh

4. How do you commute to school? (Can select multiple options)

a) Walk
b) Bicycle
c) Bus
d) Auto/Magic
e) Bike
f) Car

5. How easy or difficult it is to walk near your school area?

a) Very Easy
b) Easy
c) Neutral
d) Difficult
e) Very Difficult

6. If walking near your school is difficult, what are the reasons?

Reasons	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Vehicles move fast to make walking/crossing unsafe	☐	☐	☐	☐	☐

Illegal or unsafe parking	☐	☐	☐	☐	☐
Encroached crosswalks and sidewalks	☐	☐	☐	☐	☐
Lack of pedestrian footpath	☐	☐	☐	☐	☐
Unavailability of pedestrian signals and crossing guards	☐	☐	☐	☐	☐
Road signages are not enough	☐	☐	☐	☐	☐
Poor visibility due to parked vehicles	☐	☐	☐	☐	☐
Unsafe behaviour by users	☐	☐	☐	☐	☐
Other: _____	☐	☐	☐	☐	☐

7. Do you agree that area near your school needs improvements for safety of children?

a) Strongly Agree
b) Agree
c) Neutral
d) Disagree
e) Strongly Disagree

8. Did your school conduct any road safety programs?

a) Yes
b) No

9. Have you ever witnessed or experienced any minor or major accident in area around your school? If yes, share details in brief in last (other) option.

a) Yes
b) No