

An Investigation of the Relationships between Road Geometric Characteristics, Vehicle Speed, Road Lighting Conditions and Traffic Crash Occurrence for Road Safety Design

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Abstract

This study aims to: 1) examine the relationship between the physical characteristics of roads, road lighting conditions, vehicle speed, and road crash data; and 2) propose guidelines for geometric road design to improve road safety. The study area focuses on Sri Chan Road in Khon Kaen Municipality, Khon Kaen Province, Thailand. Field data collection included the physical characteristics of the road, vehicle speed data, road lighting conditions, and road crash data. The data was analyzed using descriptive statistics, the Accident Frequency Method, and Pearson Product Moment Correlation and Simple Linear Regression Models to explore relationships between variables. Geometric designs were also developed according to engineering principles. The study found that the mean speed of private cars was 35.73 km/h per section of the road (SD. = 4.48), and the mean speed of motorcycles was 35.24 km/h per section (SD. = 3.88). The area studied had an average number of injuries of 41.91 people/road sections. Road width was significantly related to the number of lanes, the presence of a median, and the average speed of private cars and motorcycles. The 85th percentile speed of private cars and the 85th percentile speed of motorcycles was also statistically correlated (p -value < 0.05). Additionally, the intensity of road lighting was negatively correlated with sections where severe road crashes occurred, resulting in fatalities ($r = -0.702$, p -value < 0.05). Similarly, the results of the Simple Linear Regression Models indicate that the mean vehicle speed is significantly related to the number of traffic lanes at a statistically significant level. Based on these results, geometric designs were proposed to reduce vehicle speeds, such as speed-reducing lines, speed limits near important places, and roundabouts. The findings will be submitted to relevant local authorities for future road safety improvements.

Keywords: Sri Chan Road, Crashes, Road lighting, Motorcycles, Khon Kaen, Accident Frequency Method.

1. Introduction

Road accidents or crashes are a global concern that many countries are working to address. The consequences of road accidents often lead to property damage, injuries, disabilities, or fatalities. Additionally, road accidents impact economic growth, society, and tourism. According to report of World Health Organization (WHO), approximately 1.9 million people die each year due to road accidents. The highest mortality rates from road accidents are found primarily in low- and middle-income countries. If current measures remain unchanged, road accidents will become one of the leading causes of death worldwide over the next 20 years. It is projected that road safety issues will continue to escalate. By 2030, the number of fatalities may rise to as many as 2.4 million, with an increase in traffic-accident-related disabilities. In Thailand, the road accident mortality rate is approximately 25 deaths per 100,000 people per year, placing the country among those with higher risks [1–3]. Furthermore, reports indicate that Thailand has one of the highest motorcycle-related death rates among member countries globally. According to the 2025 road accident statistics from the

Road Safety Culture Promotion Center (Thai RSC), there were 863,309 injuries and 12,536 deaths nationwide. In Khon Kaen Province, with 14,672 injuries and 252 deaths. [4]. In addition, data from the Road Safety Culture Promotion Centre (Thai RSC) indicate that, in 2024, a substantial proportion of road accidents occurred during the periods of 2:00 PM–5:59 PM (24.48%) and 6:00 PM–9:59 PM (22.82%). Combined, these two time intervals account for approximately half of all recorded accidents. [4].

Khon Kaen is a large province, with vast areas that include government offices, educational institutions, universities, shopping malls, and many residential areas. As a result, vehicular traffic is constant, and drivers frequently travel at high speeds, leading to numerous speed-related crashes [5–8]. Studies on the relationship between vehicle speed and accident statistics have shown that as vehicle speed increases, the severity of crashes also increases [9]. In Europe, dangerous or black spots are defined in various ways, as shown in **Table 1**. The most common and straightforward method used is the Accident Frequency Method, which predicts the number of crashes, injuries, and fatalities by analyzing road accident frequency per road length [10–12].

Table 1 Definitions of Dangerous Spots (Black Spots) in European Countries

Country	Definition of a Black Spot
Norway	A 100-meter section of road with at least 4 injuries or deaths within a five-year period
Belgium	A location with more than 3 accidents in 3 years
Portugal	A 300-meter road section with more than 5 accidents.
Germany	A 300-meter road section with more than 3 accidents in 1 year
United Kingdom	A 300-meter road section with more than 12 accidents in 3 years

Note: [10]

Sri Chan Road is a secondary road that has the highest number of crashes in Khon Kaen Province. Previous studies have focused on identifying black spots on Sri Chan Road within Khon Kaen Municipality, Thailand, by analyzing road accident data using the Accident Severity Method. The study, conducted with data from Khon Kaen Hospital, revealed that the most dangerous intersection is where Mittraphap Road intersects with Sri Chan Road, while the most hazardous road section is between Anamai Road and Chatapadung Road on Sri Chan Road. Local community leaders also identified the intersection near the Khon Kaen Provincial Public Health Office as a frequent site of road accidents. The main problems identified include poor road maintenance, missing traffic markings on the road surface, and a lack of proper parking and traffic regulations [13].

To address these issues, the Khon Kaen Municipality initiated the “Safe Sri Chan Road Project” to improve the safety and convenience for road users. The project involved collaboration with relevant agencies, and on April 16, 2021, a memorandum of understanding was signed between the Faculty of Industrial Education at Rajamangala University of Technology Isan, Khon Kaen Campus, the Faculty of Engineering at the Northeastern University, Khon Kaen Municipality, and the Foundation for Road Safety. The study analyzed various crash-related factors, including those related to drivers, the environment, vehicles, and the physical characteristics of the road. The project identified road sections frequently involved in crashes under the jurisdiction of the Khon Kaen Municipality and developed measures to reduce crashes and improve road safety.

2. Literature Review

The researchers reviewed relevant research studies on the solutions to dangerous spots on the road and found the following insights.

Nguyen [14] studied road safety improvements by analyzing and identifying black spots based on the safety potential of the area. The study identified appropriate black spots (high-risk areas) and

developed a five-step process for improving safety at these locations including data collection, identifying black spots in the road network, pinpointing areas with the highest crash rates, statistical testing, and summarizing and ranking the black spots for intervention. The study provided recommendations on identifying locations with the greatest potential to reduce property loss from crash. Moreover, it predicted that the safety improvement measures would be most effective in these identified areas.

Dinh [15] conducted a study on speed assessment in urban areas with a speed limit of 30 km/h. A multiple linear regression model was used for analysis, with speed as the dependent variable. The study found statistically significant relationships between speed and factors such as shoulder width, road width, and the number of lanes. The results indicated that increasing shoulder width, road width, and the number of lanes led to higher driving speeds.

Bassani [16] studied driver behavior on rural highway curves using a driving simulator, focusing on the effect of available sight distance (ASD) on speed and vehicle trajectory. The results indicated a clear linear relationship between ASD and driving speed, where increased sight distance led to higher speeds. Additionally, greater ASD reduced lateral trajectory dispersion, indicating improved vehicle control. The study also found that geometric factors such as curve radius and the distance from sight obstructions significantly influenced driver behavior. These findings highlight that enhanced visibility may encourage higher speeds, which has important implications for road safety design [16].

Anderson [17] conducted research on the relationship between road safety and the geometric characteristics of roads. The study employed models such as the negative binomial regression and Poisson regression, among others. The study found that statistically significant models showed a relationship between road safety and the radius of road curvature. Specifically, the radius of curvature must be appropriate—not too small—to ensure the safety of road usage. Phonsripradit and Phothipim [18] conducted a study on managing crash-prone spots in urban community areas: a case study of the Korat Karuhatthing community, Nai Mueang Subdistrict, Mueang Nakhon Ratchasima District in Nakhon Ratchasima Province. The study identified seven types of risk factors: uneven road surfaces, potholes, four-way intersections, three-way intersections, obstructed visibility, dimly lit areas, and curved roads. The community proposed solutions to the relevant or responsible agencies to address these risks.

Based on the review of related studies from both Thailand and abroad, we realized that data in use for analyzing accidents typically involved three years of historical data. The speed data models showed statistically significant relationships with factors such as shoulder width, lane width, and the number of lanes. Crash data models showed significant correlations

with factors such as the number of intersections and shoulder width. This study differs from previous research studies by incorporating relationships between vehicle speed, traffic crash statistics, and road physical characteristics into a single model, using linear regression for analysis.

For the context of Khon Kaen, in a previous study on black spots on Sri Chan Road within Khon Kaen, various issues were highlighted, including road crashes, risky areas, dangerous areas, and basic recommendations for improving the physical characteristics of the road to enhance road safety. The analysis utilized road accident data from Khon Kaen Hospital and local road accident experiences, collected through community leader workshops. The road crash data was analyzed using the Accident Severity Method. The study found that the most dangerous intersection was where Mittraphap Road intersects with Sri Chan Road, and the most hazardous section of the road was from Anamai Road to Chatapadung Road on Sri Chan Road. Additionally, local community leaders identified the intersection near the Khon Kaen Provincial Public Health Office as a frequent site for road crashes. The major issues identified were poor road maintenance, the absence of proper road markings, and a lack of regulations for parking and driving. The majority of these problems led to recommendations for improving road markings and road safety equipment, based on basic road safety engineering principles [13].

Summary-According to the literature that identified and analyzed solutions for black spots, the majority of the solutions involved collaboration with relevant road safety agencies. Black spots in each area have different causes or factors, but they follow a common pattern: if a specific spot or area frequently experiences road crashes, it is classified as a black spots that requires intervention from the appropriate agencies. This pattern has been confirmed by studies [19–25].

Moreover, a review of the literature indicates that previous studies have primarily focused on identifying and mitigating “black spots” using crash data and statistical models such as Poisson and Negative Binomial regression. These approaches mainly emphasize locating high-risk areas and proposing countermeasures through collaboration with relevant road safety agencies. However, a key limitation is that most studies consider factors in isolation—such as crash data or road characteristics—without integrating multiple critical dimensions, particularly road geometric characteristics, vehicle speed behavior, and lighting conditions, all of which significantly influence crash risk.

Therefore, the critical research gaps include: the absence of integrated models combining road geometry, speed, and lighting conditions and the lack of a comprehensive framework that translates analytical findings into practical geometric road design for safety improvement.

These gaps directly inform the objectives of this study: to investigate the relationships among road

physical characteristics, road lighting conditions, vehicle speed, and crash data and to develop geometric road design guidelines aligned with the Safe System Approach to enhance road safety.

3. Research Methodology

3.1 Road Section Survey

The study area is located along Sri Chan Road within Khon Kaen Municipality, covering the section from the Mittraphap Road intersection to the Prachasamosorn Road intersection. The total length of this road section is 4.73 kilometers, classified as a secondary road. The survey examined the physical characteristics of the road, including the length of the road, the number of lanes, and the roadway width. Additionally, vehicle speed was measured, including the 85th percentile speed and the mean speed. Road lighting conditions (Street light) and crash data in the area were also collected. The selected variables are significant in explaining accident risk from both engineering and behavioral perspectives. Road geometric characteristics, including length of roads, number of lanes, and roadway width, directly influence traffic capacity, maneuverability, and driver perception. These factors are closely associated with speed choice and conflict opportunities. Vehicle speed variables, particularly the 85th percentile speed and mean speed, are widely recognized indicators of operating speed and driver behavior, reflecting both compliance and risk-taking tendencies.

In addition, road lighting conditions are crucial environmental variables affecting visibility, especially during nighttime, influencing driver reaction time and hazard detection. Crash data provides empirical evidence of safety performance and enables the identification of high-risk locations and contributing factors. Collectively, these variables form an integrated framework for analyzing road safety and support the development of effective geometric design guidelines, as detailed in **Table 2**, which defines all variable indicators used in this study.

Table 2. Variable Description

No	Variable	Description
1	PC85th	85th percentile speed of private cars (km/h)
2	PCavg	Mean speed of private cars (km/h)
3	MC85th	85th percentile speed of motorcycles (km/h)
4	MCavg	Mean speed of motorcycles (km/h)
5	Diff85th	Difference in 85th percentile speed between private cars and motorcycles (km/h)
6	Diffavg	Difference in mean speed between private cars and motorcycles (km/h)
7	L	Length of roads (m)
8	NL	Number of lanes (lanes)

Table 2. Variable Description (cont.)

No	Variable	Description
9	RW	Roadway width (m)
10	TI	Traffic island (1 = present; 0 = absent)
11	SL	Street light (Lux)
12	IN	Number of injuries (Persons)
13	D	Sections with severe crashes (1 = fatality occurred, 0 = no fatality)

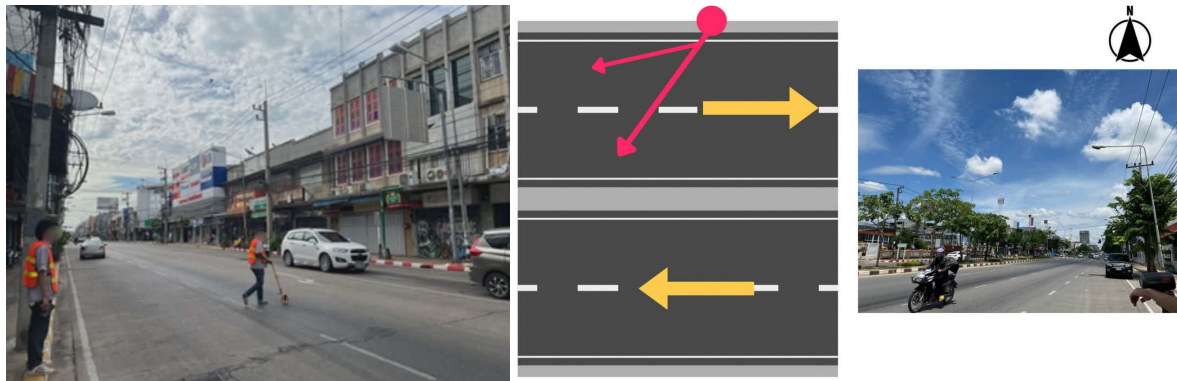
3.2 Spot Speed Survey

Spot speed refers to the speed of a vehicle at a specific point on the road. In this study, speed data was collected

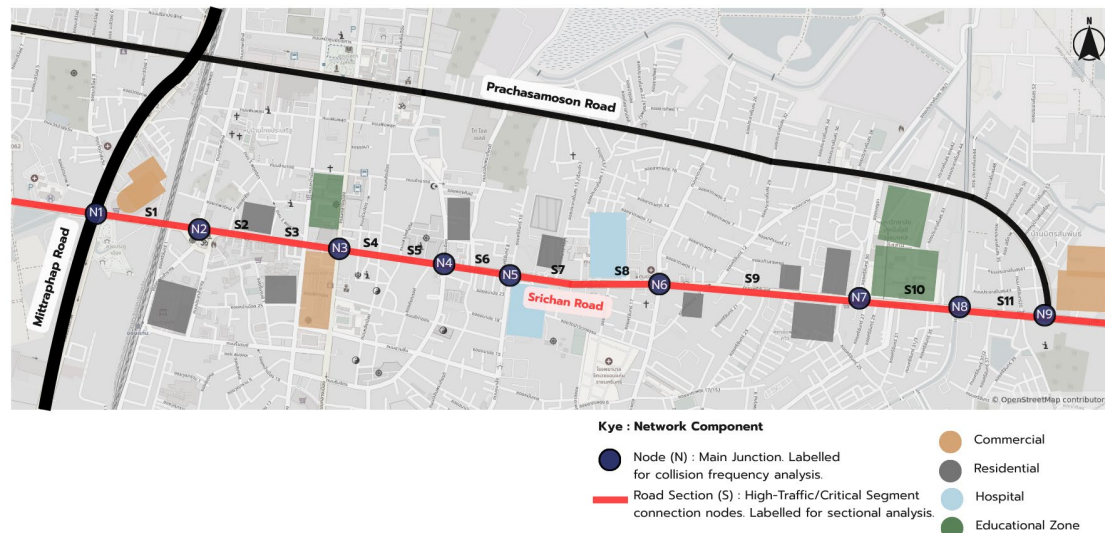
by categorizing vehicles into two types: motorcycles and private cars [9]. The speed data was collected during non-peak hours (from 2:00 PM to 3:30 PM) using a radar gun. Speed samples were randomly collected, with speed data being recorded in two directions at each survey point. The survey points were labelled from S1 to S11. (As shown in **Figure 1** and **Figure 2**)

3.3 Crash Analysis Method

In this study, the Accident Frequency Method was used to analyze accidents [26–27]. This method involves counting the number of crashes that occurred on specific road sections. Road crash data from Khon Kaen Central Hospital for the years 2020–2022 were used for the analysis in **Table A1**.

**Figure 1.** Data Collection

NETWORK ANALYSIS TRAFFIC ACCIDENT METHOD

**Figure 2.** Study Area

3.4 Road Lighting Data Collection

In 2024, road crashes in Khon Kaen Province occurred most frequently between 14:00 and 21:59. Given that a significant portion of these crashes occurred during twilight and nighttime hours, assessing roadway visibility and lighting conditions became essential. Therefore, this study focused on evaluating the performance of street

lighting along Sri Chan Road. The evaluation of street lighting performance was conducted based on illuminance (E) measured on the road surface, expressed in lux (lx). The measurements aimed to determine whether the existing lighting conditions meet the minimum safety requirements defined by relevant standards. Illuminance measurements were carried out using a calibrated lux

meter under a static measurement system, where the sensor was positioned horizontally on the road surface. Measurement points were established at 20-meter intervals along the roadway, with additional emphasis on intersection areas, where lighting conditions are critical for traffic safety. The measurement layout was designed to ensure representative sampling of lighting conditions across the study area, as illustrated in **Figure 3**. All measurements were conducted under normal operating conditions of the street lighting system during nighttime, with all luminaires functioning properly. The collected data were compared with the minimum illuminance levels required for safety, as specified by the Department of Highways. The criteria used in this study are summarized in **Table 3**, which classifies road types into arterial roads,

collector roads, intersections, and local roads, along with their corresponding minimum illuminance requirements. The adequacy of the street lighting system was evaluated by comparing the measured illuminance values at each point with the specified minimum thresholds. Locations with illuminance values lower than the standard were identified as areas requiring improvement. [28]

Table 3. Road Lighting Requirements (Lux)

Road type	Minimum levels for Safety
Arterial Road	21.5 Lux
Collector Road	13.0 Lux
Intersection	21.5 Lux
Local road	9.7 Lux



Figure 3. Street lights Data Collection

3.5 Variable Correlation Analysis and Simple Regression Models

From **Table 2**, descriptive statistics such as the mean, frequency, and 85th percentile were analyzed. To assess the relationships between two variables, Pearson's correlation and simple regression models coefficient were used. The statistical tests were conducted at a 95% confidence level [29].

3.6 Geometric Road Design for Road Safety

The geometric design of roads for safety purposes was carried out by incorporating field data and correlation analysis results to develop road safety measures [30]. The design process was performed using computer software, and the steps were as follows:

1. Examine road functions and the level of traffic service provided.
2. Check the horizontal and vertical alignments of the road.
3. Design and draft plans using computer software based on the field data.
4. Identify and design conflict points that may occur.
5. Design locations for installing signs or road markings as part of the safety measures.
6. After completing the design, the researchers reviewed the design according to the road safety audit manual provided by the Department of Rural Roads.

4. Results and discussion

4.1 Results of the Basic Data Survey of the Study Area

The survey of the physical characteristics of the roads found that, across all 11 road sections (S1–S11), the average road length was 0.43 kilometers per section ($SD = 0.29$). The average road width was 17.30 meters per section ($SD = 2.73$), and the average number of lanes was 6.36 lanes per section ($SD = 1.96$). Additionally, 7 out of the 11 road sections had a median strip, accounting for 64% of the sections surveyed as shown in **Table A2**.

Results of the Vehicle, Environmental Factors, and Road Accident Data Survey. The key findings are as follows: The average speed of private cars (PCavg) was 35.73 km/h per road section ($SD = 4.48$). The average speed of motorcycles (MCavg) was 35.24 km/h per road section ($SD = 3.88$). The average difference in mean speed (Diffavg) was 0.48 km/h per road section ($SD = 2.66$). The 85th percentile speed for private cars (PC85th) averaged 41.82 km/h per road section ($SD = 5.91$). The 85th percentile speed for motorcycles (MC85th) averaged 42.70 km/h per road section ($SD = 5.74$). The average difference in the 85th percentile speed (Diff85th) was -0.88 km/h per road section ($SD = 4.35$).

In addition: The average road lighting intensity was 7.82 Lux ($SD = 1.66$). The average number of injuries per road section was 41.91 cases ($SD = 40.54$). There were 5 road sections with fatalities, representing 45.50% of the study area as shown in **Table A3**.

4.2 Study of Correlations

Table A4 shows the correlation between the physical characteristics of the road and vehicle, environmental, and road crash data. The analysis found the following relationships:

1. The length of road sections is correlated with the number of injuries from road crashes.
2. The roadway width is correlated with the number of lanes, the presence of a median strip, and the average speed of both private cars and motorcycles. The 85th percentile speed of private cars is also significantly correlated (p -value < 0.05). These correlations are positive, meaning that as the roadway width increases, the average speed of both private cars and motorcycles also increases.

Additionally, **Table A4** shows a significant correlation between the intensity of road lighting and the sections with fatal road crashes ($r = -0.702$, p -value < 0.05). This result indicates that lower lighting intensity is associated with an increased likelihood of severe crashes resulting in fatalities.

4.3 Study of Simple Linear Regression Models

Table A5 shows the results of eight Simple Linear Regression models. The findings are best interpreted by vehicle type. For private cars, the best-fitting model indicates a statistically significant relationship between the mean speed of private cars and the number of traffic lanes (Model 1), yielding an R Square value of 0.37, an Adjusted R Square value of 0.30, $F = 5.296$, and $p < 0.05$. For motorcycles, the most appropriate model also reveals a statistically significant relationship between the mean speed of motorcycles and the number of traffic lanes (Model 2), with an R Square value of 0.32, an Adjusted R Square value of 0.20, $F = 3.296$, and $p < 0.05$. These findings are consistent with previous studies and suggest that, as road width increases and the number of traffic lanes expands, vehicles on such roads tend to operate at higher speeds. [16]

4.4 Geometric Road Design for Road Safety

Based on the results of the correlation analysis between road width and vehicle speed, which showed statistically significant relationships, the researchers suggest implementing measures to manage vehicle speed in certain road sections. These measures could involve geometric road designs aimed at slowing down vehicles, which would help encourage drivers to reduce their speed.

Additionally, the study found a statistically significant correlation between road lighting intensity and road sections with fatal crashes. Therefore, it is recommended to design appropriate road lighting systems that ensure clear visibility for drivers at night. The design should follow the guidelines outlined in the

Road Safety Audit and Improvement Manual provided by the Department of Rural Roads to enhance safety.

4.4.1 Urban Area Design

The most effective approach for urban road design is to implement speed-reduction measures by combining various methods, such as roundabouts, narrowing the road, speed bumps, zigzag lines, and speed-reduction lines. Even if not all of these measures can be implemented, minor road modifications can still encourage drivers to reduce their speed. (As shown in **Figure 4–5**) And recommended installation locations for the measures are shown in **Figure A1**.

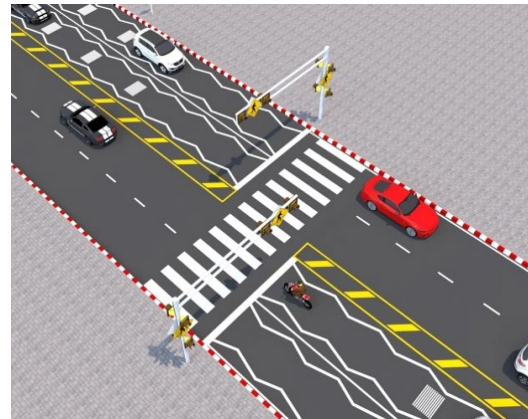


Figure 4. Design of Zigzag Lines on the Road



Figure 5. Design of Roundabouts

4.4.2 Designation of Low-Speed Zones:

Designating special low-speed zones in areas with high pedestrian traffic can significantly reduce the severity of road injuries. This measure is particularly important near schools, universities, and hospitals. For example, schools should have pedestrian crossings with traffic lights to ensure the safety of children, as shown in **Figure 6**. And recommended installation locations for the measures are shown in **Figure A1**.

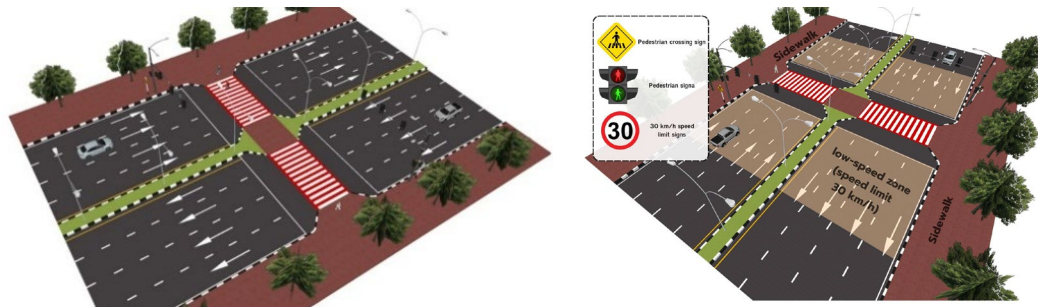


Figure 6. Safe Pedestrian Crossing

4.4.3 Road Lighting Design

We found that improving road lighting enhances nighttime driving capabilities by providing clear visibility of the road and roadside objects, allowing drivers to respond quickly in emergencies, thereby reducing the likelihood of crashes. When designing and installing road lighting, designers must consider actual road usage. Effective and efficient street lighting should take into account the economic, social, and safety benefits to road users. The three key factors to consider are:

1. Type of light bulb.
2. Poles and pole bases. (as shown in **Figure 7–8**)
3. Location and landscape positioning.



Figure 7. Design of Poles and pole bases for Street light



Figure 8. Alternative street lighting configuration for undivided roads without a central median, using roadside pole installation.

4.5 Discussion

The study found that the average number of injuries in the study area was 41.91 cases per road section. Using Belgium's criteria for black spots, where locations with more than three crashes over three years are considered hazardous, this indicates that the entire study area on Sri Chan Road is classified as dangerous [10]. The correlation analysis between road physical characteristics, environmental factors, vehicle speed, and road crash data shows a statistically

significant relationship between vehicle speed and road characteristics. This finding aligns with previous research, showing that the speed of private cars and motorcycles is correlated with road width and the number of lanes. The study covered areas in Thailand, Laos, and Cambodia, demonstrating that the presence of a median strip also has a positive correlation with vehicle speed [31].

Additionally, the study found that the difference in speed between motorcycles and private cars was significantly correlated with road sections where fatal crashes occurred, aligning with previous research showing that large speed differences between motorcycles and private cars increase the likelihood of severe crashes [31]. Given the widespread use of motorcycles in Thailand, where they share the road with other vehicle types, large speed differences can increase crash risk [31].

Currently, road crash prevention agencies emphasize the importance of street lighting, as there is a statistically significant correlation between road lighting, humidity, and temperature [28]. Previous studies have shown that crashes in Khon Kaen often occur at night. This study also found a relationship between street lighting and road sections with fatalities, emphasizing that sufficient lighting is crucial for safe driving across all vehicle types and ages [6–7].

Through analysis of geometric road design for road safety, the results showed that the most dangerous road section on Sri Chan Road in Khon Kaen Municipality, with the highest number of injuries, was section S8 (from Anamai Road to Chatapadung Road). This finding aligns with previous research identifying hazardous spots such as the intersection near the Khon Kaen Provincial Public Health Office, the area in front of Khon Kaen Hospital, and the U-turns in front of Sentosa Mall and the Irrigation Department Office [32].

Previous studies suggested various safety improvements for the area around Khon Kaen Hospital Market, including standardizing traffic markings, designating parking areas to regulate traffic flow, strictly enforcing laws against double parking, and adding motorcycle lanes to enhance safety for motorcyclists. This study also recommends creating safe pedestrian crossings in front of Khon Kaen Hospital and narrowing lanes to reduce vehicle speed. Additionally, intersection management should include

dedicated motorcycle waiting areas (bike boxes) to improve the convenience and safety of motorcyclists [33–34].

The findings also suggest implementing traffic calming measures such as speed bumps, speed humps, and safe pedestrian crossings, along with roundabouts to manage vehicle speed. Prior research shows that reducing lane width can effectively lower vehicle speeds [35].

To further improve road safety, we recommend repainting traffic lines to meet standardized guidelines, with a particular focus on adding speed-reducing markings before U-turns and ensuring the installation of clearer, more visible warning signs [18]. Additionally, road lighting should meet the required standards to enhance visibility for drivers.

The study's findings regarding insufficient road lighting were reported to local government authorities in Khon Kaen, prompting corrective actions by the Khon Kaen Municipality to address the issue and improve safety conditions as shown in **Figure 9**.



Figure 9. Road Safety Committee Meeting in Khon Kaen

5. Conclusion and Recommendations

The study examined the relationship between road physical characteristics, road lighting conditions, vehicle speed, and road crash data, and proposed geometric road design solutions for road safety. The findings show that private cars travel at higher average speeds than motorcycles, and the average number of injuries per road section is 41.91 people/road sections. Road width is correlated with the number of lanes, the presence of a median strip, and the average speed of both private cars and motorcycles. Additionally, vehicle speed differences and road lighting intensity are correlated with fatal crash-prone road sections. Similarly, the results of the Simple Linear Regression Models indicate that the mean vehicle speed is significantly related to the number of traffic lanes at a statistically significant level. Based on these findings, the study proposes geometric designs to reduce speed, including speed-reduction lines, speed limits near key locations, street lighting installation, and roundabouts.

5.1 Recommendations of the study

1. In-depth research on the causes of road crashes using Field Failure Analysis (FFA).

2. Submission of findings to local authorities to improve road safety.
3. Further research into traffic management [36], traffic calming, black spot treatment, and road safety audits.

5.2 Limitations of the study

The road traffic crashes data obtained solely from Khon Kaen Hospital may underestimate the actual number of accidents occurring in the study area. Minor traffic crashes, in particular, are often underreported because injured individuals may not seek medical treatment or hospital services. Therefore, future studies should consider integrating accident information from three major national databases: 1) Ministry of Public Health, 2) Royal Thai Police, and 3) Road Accident Victims Protection Company Limited. The integration of these multi-source datasets would improve data completeness, increase the accuracy of accident estimations, and reduce the risk of missing or underreported cases.

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8. APPENDIX

8.1 Appendix A: Historical Crash Records

This appendix provides comprehensive historical safety data for the study area. **Table A1** details the annual number of injuries and fatalities recorded across individual road sections (S1 to S11) from 2020 to 2022. This information is essential for establishing baseline safety performance, identifying high-risk locations (black spots), and evaluating the spatial distribution of traffic accidents along Srichan Road.

Table A1. Presents the statistical data on the number of injuries and fatalities in the study area (road sections).

Road sections (S)	Number of injuries and fatalities (persons)							
	2020		2021		2022		All	
	Injuries	Fatalities	Injuries	Fatalities	Injuries	Fatalities	Injuries	Fatalities
S1-Srichan Road from Mittraphap Road to the railway	0	0	1	0	0	0	1	1
S2- Srichan Road from Theparak Road to Na Muang Road	18	0	12	0	18	1	48	1
S3-Srichan Road from Na Muang Road to Klang Muang Road	1	0	0	0	3	0	4	0
S4 -Srichan Road from Klang Muang Road to Lang Muang Road	6	0	3	0	5	0	14	0
S5 -Srichan Road from Lang Muang Road to Lop Muang Road	11	0	8	0	9	0	28	0
S6 -Srichan Road from Lop Muang Road to Chaloe Phrakiat Road	7	0	10	0	13	0	30	0
S7 -Srichan Road from Chaloe Phrakiat Road to Anamnai Road	3	0	0	0	0	0	3	0
S8 -Srichan Road from Anamnai Road to Chataphudung Road	38	0	32	0	53	0	123	0
S9 -Srichan Road from Chataphudung Road to the Highways Department	43	0	26	1	24	0	93	1
S10 -Srichan Road from the Highways Department to the Irrigation Canal	36	0	22	1	22	0	80	1
S11 -Srichan Road from Khlong Chonlaprathan to Prachasamoson Road	11	1	21	0	5	0	37	1

8.2 Appendix B: Roadway Physical Characteristics and Infrastructure Survey

This appendix compiles the physical attributes of the studied road segments. **Table A2** outlines critical geometric and infrastructure characteristics—including road distance, road width, presence of traffic islands, and number of traffic lanes—for each section. These parameters are crucial for assessing how roadway design elements influence traffic operations and safety conditions.

Table A2. Provides detailed results of the survey on the physical characteristics of the roads.

Characteristics of the roads				
Road sections (S)	Road distance (km) -L	Road width (m)-RW	Traffic island -I	Number of traffic lanes-NL
S1	0.27	10.1	Yes	6.00
S2	0.55	10.1	No	4.00
S3	0.16	10.1	No	4.00
S4	0.24	10.1	No	4.00
S5	0.35	10.1	No	4.00
S6	0.16	17.3	Yes	8.00
S7	0.2	14.8	Yes	8.00
S8	0.75	14.9	Yes	8.00
S9	1.1	14.7	Yes	8.00
S10	0.5	14.7	Yes	8.00
S11	0.45	14.2	Yes	8.00

8.3 Appendix C: Traffic Operational and Environmental Factors

This appendix presents empirical data regarding vehicle speeds and environmental variables. **Table A3** details the mean and 85th percentile speeds for private cars and motorcycles, speed differentials, street lighting availability, and crash frequencies per section. This dataset is necessary for analyzing speed behavior patterns and environmental interactions with road safety.

Table A3. Provides a detailed breakdown of the vehicle and environmental factors along with road crash data.

Road sections (S)	Vehicle and environmental factors							IN	D
	PC _{avg}	MC _{avg}	Diff _{avg}	PC _{85th}	MC _{85th}	Diff _{85th}	Street light		
S1	33.88	32.22	1.65	38.00	39.00	-1.00	6.00	1.00	Yes
S2	34.00	32.70	1.30	39.30	37.65	1.65	7.00	48.00	Yes
S3	31.53	31.95	-.42	36.80	35.65	1.15	10.00	4.00	No
S4	28.88	29.28	-.40	33.23	33.03	.20	11.00	14.00	No
S5	32.13	34.95	-2.83	37.65	48.30	-10.65	8.00	28.00	No
S6	33.78	34.10	-.32	38.65	41.30	-2.65	7.00	30.00	No
S7	42.08	41.22	.85	47.73	48.58	-.85	9.00	3.00	No
S8	36.18	41.05	-4.88	43.23	49.23	-6.00	8.00	123.00	No
S9	37.80	34.58	3.22	44.30	44.23	.08	8.00	93.00	Yes
S10	42.83	39.30	3.53	49.03	44.45	4.58	6.00	80.00	Yes
S11	39.95	36.35	3.60	52.15	48.30	3.85	6.00	37.00	Yes

8.4 Appendix D: Statistical Correlation and Regression Models

This appendix provides the statistical foundation supporting the variable relationships and predictive modeling. **Table A4** displays the bivariate correlation matrix among all geometric, operational, and safety variables, identifying multicollinearity and significant associations. Furthermore, **Table A5** presents the development of speed models via simple linear regression, establishing quantitative relationships between speed characteristics and roadway design variables (such as lane count and road width).

Table A4. Correlation Values between Variables

	L	RW	I	NL	PC _{avg}	MC _{avg}	Diff _{avg}	PC _{85th}	MC _{85th}	Diff _{85th}	SL	IN	D
L	1	.253	.288	.352	.308	.255	.146	.348	.340	.024	-.218	.842**	.476
RW		1	.793**	.917**	.634*	.640*	.133	.612*	.555	.098	-.319	.462	-.024
I			1	.954**	.725*	.617*	.319	.682*	.558	.189	-.564	.360	.311
NL				1	.787**	.714*	.283	.767**	.640*	.197	-.468	.473	.213
PC _{avg}					1	.808**	.505	.947**	.674*	.396	-.508	.349	.419
MC _{avg}						1	-.101	.754**	.853**	-.101	-.296	.489	-.053
Diff _{avg}							1	.494	-.110	.815**	-.425	-.126	.785**
PC _{85th}								1	.721*	.406	-.526	.376	.443
MC _{85th}									1	-.340	-.399	.436	.004
Diff _{85th}										1	-.187	-.064	.596
SL											1	-.263	-.702*
IN												1	.234
D													1

*. Correlation is significant at the 0.05 level

**. Correlation is significant at the 0.01 level

Table A5. Speed models developed by simple linear regression

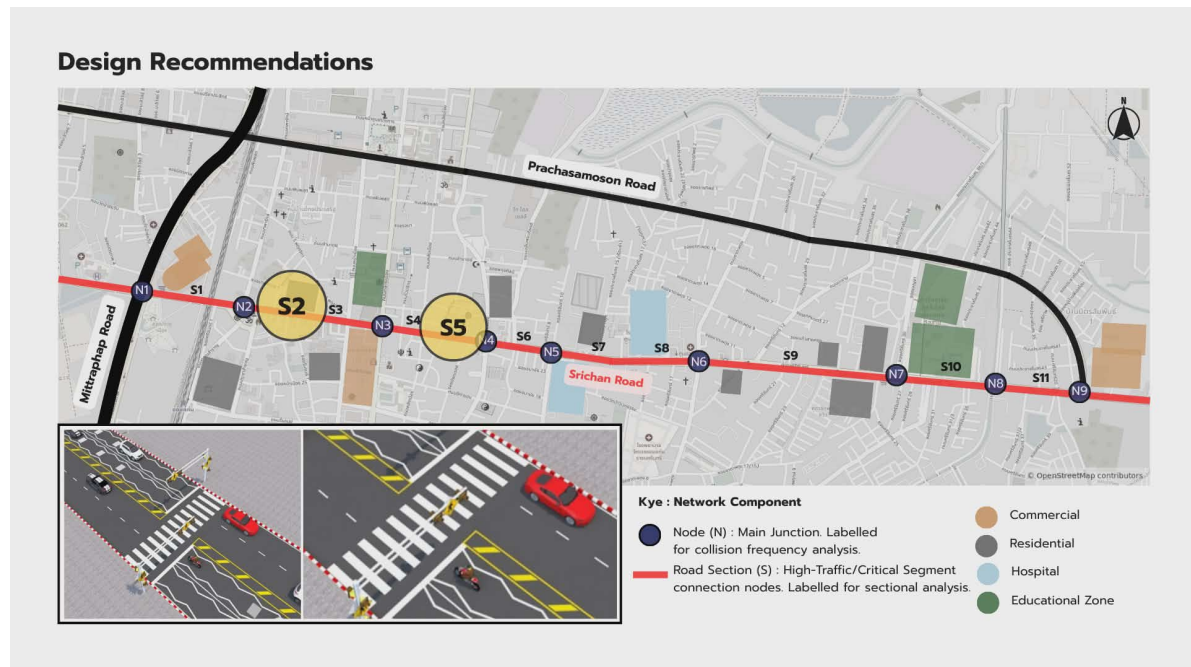
Variable	Estimated coefficient	Std. Error	t	Sig.
Dependent variable: 85th percentile speed of private cars (km/h)				
Road width (m)	1.326	0.572	2.320	0.045
Constant	24.813	7.482	3.316	0.009
R ² = 0.374, Adjusted R ² =0.305				
Number of traffic lanes	2.307	4.274	3.581	0.006
Constant	27.144	0.644	6.352	0.000
R ² = 0.588, Adjusted R ² =0.542				
Dependent variable: Mean speed of private cars (km/h)				
Road width (m)	1.042	0.424	2.459	0.036
Constant	22.357	5.548	4.030	0.003
R ² = 0.402, Adjusted R ² =0.335				
Number of traffic lanes	1.769	0.469	3.827	0.004
Constant	24.296	3.114	7.803	0.000

Table A5. Speed models developed by simple linear regression (cont.)

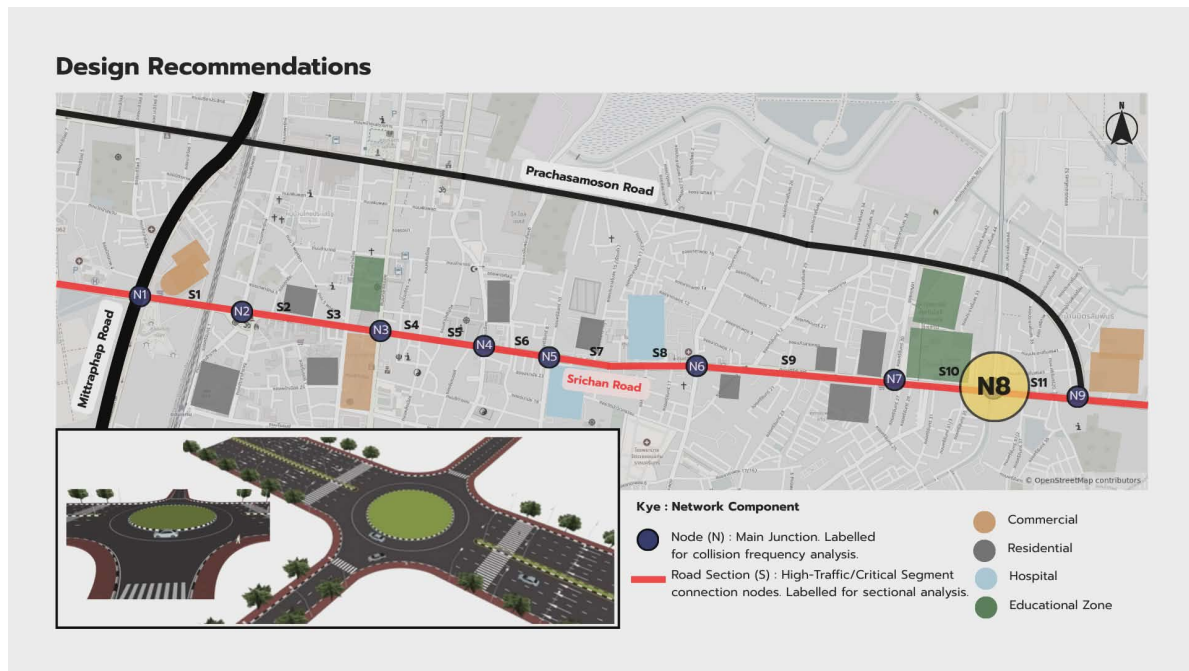
Variable	Estimated coefficient	Std. Error	t	Sig.
$R^2 = 0.619$, Adjusted $R^2 = 0.577$				
Traffic island	6.437	2.040	3.155	0.012
Constant	31.631	1.628	19.435	0.000
$R^2 = 0.525$, Adjusted $R^2 = 0.472$				
Dependent variable: 85th percentile speed of motorcycles (km/h)				
Number of traffic lanes	1.871	0.749	2.497	0.034
Constant	30.796	4.971	6.196	0.000
$R^2 = 0.409$, Adjusted $R^2 = 0.344$				
Dependent variable: Mean speed of motorcycles (km/h)				
Road width (m)	0.913	0.365	2.500	0.034
Constant	23.535	4.779	4.924	0.001
$R^2 = 0.410$, Adjusted $R^2 = 0.344$				
Number of traffic lanes	1.413	0.462	3.058	0.014
Constant	26.253	3.066	8.564	0.000
$R^2 = 0.510$, Adjusted $R^2 = 0.455$				
Model 8				

8.5 Appendix E: Guidelines and Study Area Mapping

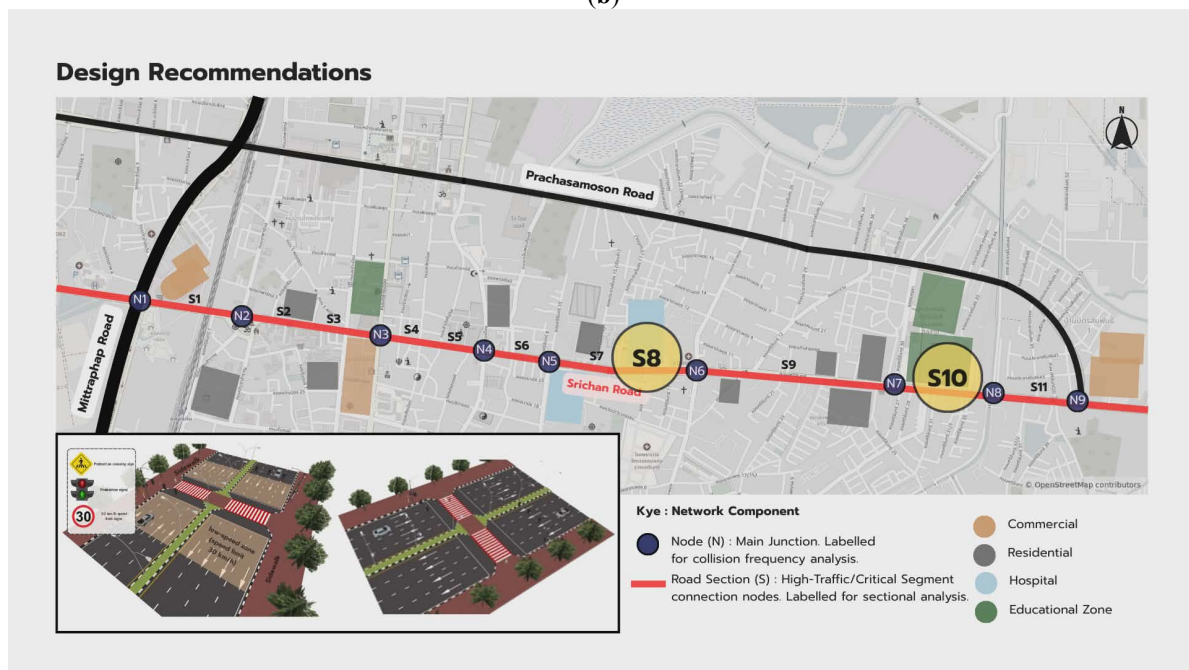
This appendix supplies supplementary visual references critical for contextualizing the research framework. **Figure A1** illustrates standard guidelines for urban traffic-calming measures, area design, and low-speed zone designation, providing practical benchmarks for mitigating safety risks. Furthermore, **Figure A2** maps the geographical context of the study area, offering spatial clarity on the evaluated road sections along Srichan Road, and demonstrates how the proposed lane design and speed-reduction measures at S2 and S5 are particularly suitable for high-density commercial intersections with frequent vehicle–pedestrian interactions. By encouraging lower approach speeds, improving visibility, and reducing conflict points, these designs enhance driver reaction times and mitigate both the likelihood and severity of traffic accidents.



(a)



(b)



(c)

Figure A1 Guidelines for installing urban measures, area design, and designation of low-speed zones: (a) Urban traffic-calming measures; (b) Area-design guidelines; and (c) Designation of low-speed zones.

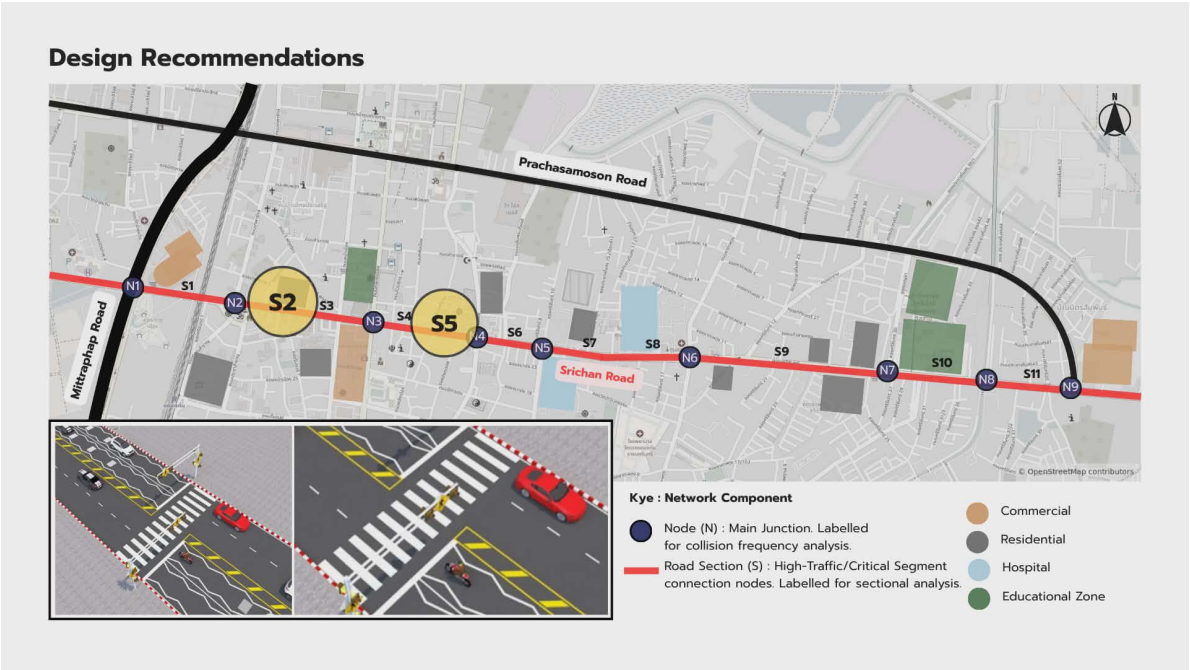


Figure A2 Study Area