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Evaluation of Factors Influencing Bicycle Accidents as an Effort to Improve Transportation Safety and Sustainability in Surabaya City

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Abstract

Traffic accidents involving cyclists remain a pressing urban safety issue in Indonesia, where mixed traffic patterns increase risks for non-motorized road users. The growing number of cyclists in Surabaya underscores the need for proper infrastructure planning that ensures both safety and mobility efficiency. This research aims to analyze the factors contributing to bicycle accidents and propose appropriate bicycle lane design recommendations based on road function, geometric characteristics, and traffic performance. The study employs a quantitative-descriptive method, combining accident data analysis, road geometry assessment, and Level of Service (LOS) evaluation. Findings reveal that cyclist accidents are predominantly influenced by socioeconomic factors, low safety awareness, lack of protective equipment, and insufficient road space allocation. Young cyclists with minimal safety discipline are particularly vulnerable, especially during morning hours on arterial roads with high traffic volumes. Based on the LOS and road classification, arterial roads such as Ahmad Yani, Darmo, and Ngagel require Type C (bike road) lanes with full physical separation from motorized traffic, while collector roads such as Ir. H. Soekarno, Kedung Cowek, and Mastrip are suitable for Type A (bike lane) configurations located alongside vehicle lanes. These results highlight that context-sensitive bicycle lane design—tailored to traffic characteristics and road capacity—is essential for promoting cyclist safety, reducing accident rates, and supporting sustainable urban mobility in Surabaya.

Keywords: Safety, Bicycle Lanes, Sustainable Transportation

INTRODUCTION

Frequent transportation problems arising from road traffic regulations, which are often ignored by drivers, frequently lead to accidents (Ahmed et al., 2023). Indonesia's mixed traffic pattern results in a high risk of accidents (Davinci Nababan, 2025; Junirman & Oneyama, 2021; Sari et al., 2024). The city of Surabaya saw an increase in the number of accidents from 862 in 2022 to 920 in 2023 and then to 1,335 in 2024.

Cycling has become a global trend in sustainable transportation, with a significant increase in bicycle use in major cities around the world (Buehler & Pucher, 2022; Chen et al., 2022). According to Millard-Ball (2025) & Nello-Deakin (2021), the global number of cyclists has risen by over 45% in the past decade, particularly in cities such as Copenhagen, Amsterdam, and Tokyo, where cycling accounts for more than 30% of daily urban trips. However, this rise is accompanied by a worrying increase in cyclist fatalities. The Guo (2025) reported that cyclist deaths globally increased by 9% between 2010 and 2020, largely due to poor infrastructure design and unsafe mixed-traffic conditions. In Southeast Asia, the issue is even more pronounced because most cities, including Surabaya, have not yet developed integrated infrastructure to separate bicycles from motorized vehicles (Irawan, 2022; Peters, 2023). These global data underscore the urgent need for context-sensitive bicycle infrastructure design that integrates both engineering safety and human behavioral factors (Al Humdan, 2025; Staphorst, 2024).

Reducing the losses resulting from road problems requires implementing environmentally sustainable transportation solutions (Badi et al., 2023; Musa et al., 2023; Shah et al., 2021). Transportation development and land use play a crucial role in government policies and programs (Surya et al., 2021; Verma et al., 2021). According to Fatorachian(2025) & Ma (2021), one component of sustainable urban transport in *Transportation Demand Management (TDM)* is maximizing the efficiency of the urban transportation system by limiting unnecessary private vehicle use and encouraging more effective, healthy, and environmentally friendly modes of transportation, such as public transport and non-motorized vehicles like bicycles.

The physical characteristics of bicycles, which differ from motorized vehicles, require a higher level of safety for their users. However, in practice, conflicts often arise over road space, which tends to be dominated by motorized vehicles. This situation occurs because road designs often provide ample access for motorized vehicles without considering the needs and safety of cyclists as other road users (Morris et al., 2021). Such conditions increase the risk of accidents for cyclists, especially in urban areas with high mobility rates like Surabaya (Suryani et al., 2021). Bicycles are an environmentally friendly and energy-efficient mode of transportation that contributes to the realization of a sustainable transportation system (Shah et al., 2021; Upadhyay et al., 2024). Therefore, improving cyclist safety requires attention in urban transportation planning and management to achieve a balance between mobility efficiency and the safety of all road users (Oskarbski et al., 2021; Rui & Othengrafen, 2023).

Given these issues, understanding the factors causing cyclist accidents is essential for prioritizing alternatives for improving cyclist safety and designing dedicated bicycle lanes in Surabaya (Handayani et al., 2022). This, in turn, allows for appropriate and targeted safety improvements to prevent and reduce the fatality rate of accidents (Berhanu et al., 2023).

Previous studies have contributed valuable insights into the causes of cyclist accidents and infrastructure needs, yet they also reveal conceptual and methodological gaps. Rahman Chong (2025) analyzed cyclist safety in Kuala Lumpur and found that poor geometric design—such as narrow lanes and a lack of signage—was a major contributor to accidents. However, their study was limited to geometric parameters and did not incorporate behavioral factors. Meanwhile, Hossein Sabbaghian (2024) emphasized that behavioral aspects—such as helmet use, visibility, and cyclist awareness—significantly affect accident risk, but their research lacked spatial and geometric analysis to translate findings into infrastructure design. Unlike previous studies that treat engineering and behavior separately, this research provides a comprehensive framework for infrastructure planning that considers both traffic performance and human safety behavior, making it highly relevant for developing cities with complex mixed-traffic systems.

The purpose of this study is to analyze the factors influencing bicycle accidents in Surabaya and to propose a context-based bicycle lane design that balances cyclist safety with traffic flow efficiency. The findings are expected to provide practical implications for policymakers and urban planners in Indonesia in formulating sustainable transport policies, while also contributing to academic discourse by offering a novel integrative approach that links geometric design and behavioral safety for accident prevention.

METHOD

Bicycle lane design not only serves as a physical element of the road but also as a crucial instrument in creating a safe, comfortable, and sustainable transportation system. Determining the type of bicycle lane must take into account the geometric characteristics of the road, traffic volume, and interactions between road users.

According to the Indonesian Road Traffic Management Association (MKJI) (1997), the function of roads is to provide safe and comfortable transportation services. The most important factors in traffic planning are traffic volume, free-flow speed, capacity, degree of saturation, throughput, and level of service.

a. Volume (Q)

Vehicle volume is calculated using the following equation: (MKJI, 1997)

$$Q = \frac{N}{T} \text{ ....(1)}$$

Where:
Q = Volume (vehicles/hour)
N = Number of vehicles (vehicles)
T = Observation time (hours)

b. Free Flow Velocity (FV)

The equation for determining free flow velocity has the following general form:

$$FV = (FV_o + FV_W) \times FFV_{SF} \times FFV_{CS} \text{.......................(2)}$$

Where:

FV	= Free-flow speed of light vehicles under field conditions (km/h)
FVo	= Basic free-flow speed of light vehicles on the observed road
FVW	= Speed adjustment for road width (km/h)
FFVSF	= Adjustment factor for side obstacles based on shoulder width or curb distance
FFVCS	= Speed adjustment factor for city size

c. Capacity

The basic equation for determining capacity is as follows: (MKJI, 1997)

$$C = Co \times FCw \times FCsp \times FC_{SF} \times FC_{CS} \text{.......................(3)}$$

Where:
C = road section capacity (smp/hour)
Co = base capacity (smp/hour)
FCw = lane width adjustment factor
FCsp = directional separation adjustment factor
FCSF = side friction adjustment factor
FCCS = city size adjustment factor

d. Degree of Saturation or Volume Capacity Ratio (VCR)

The VCR value is obtained from the following equation: (Morlok, 1991)

$$VCR = \frac{V}{C} \text{.......................(4)}$$

Where:

VCR = Degree of Saturation / Volume Capacity Ratio
V = Vehicle Volume (smp/hour)
C = Vehicle Capacity (smp/hour)

e. Travel Speed

The basic equation for determining travel speed is as follows: (MKJI, 1997)

$$V= \frac{L}{TT} \text{ ....(5)}$$

Where:
V = Average speed of light-duty vehicles (km/h)
L = Segment length (km)
TT = Average travel time of light-duty vehicles along the segment (hours)

f. Level of Service (LOS)

A qualitative measure that reflects drivers' and passengers' perceptions of the characteristics of operational conditions within the traffic flow.

Table 1. Road Level of Service Characteristics

V/C Ratio	LOS	Information
<0,60	A	Current current, low volume, high speed
0,60 – 0,70	B	Stable current, limited speed, volume suitable for city roads
0,70 – 0,80	C	Steady current, speed affected by traffic, volume suitable for city roads
0,80 – 0,90	D	Near-unstable current, low speed
0,90 – 1,00	E	Unstable current, low speed, solid volume or close to capacity
>1,00	F	Blocked current, low speed, volume above capacity, many stops

Source: MKJI, 1997

Design of Bicycle Lanes

a. Type A (bicycle lane) is typically used on roads with high traffic volumes and limited space, where the bicycle lane is placed at the edge of the road with dividing markings.
b. Type B (bicycle path) is a lane physically separated from motorized traffic, providing a higher level of safety for cyclists.
c. Type C (bicycle road) is used in low-traffic areas or residential areas, where cyclists and motorized vehicles can safely share road space.

Selecting the appropriate lane type is expected to minimize the potential for conflict between road users, reduce accidents, and encourage people to switch to more environmentally friendly and sustainable modes of transportation.

RESULTS AND DISCUSSION

General Overview of the City of Surabaya

Geographically, the city of Surabaya is located between 07°09'00" - 07°21'00" South Latitude and 112°3600" - 112°54'00" East Longitude. Surabaya is the capital of East Java Province and covers an area of 326.36 km² (BPS Surabaya City, 2024). According to the Population and Civil Registration Office, the population of Surabaya is 150,670, with a population density of 4,500 people/km².

Characteristics of Bicycle Accidents in the City of Surabaya

a. Socio-Economic Characteristics

Table 2. Socio-Economic Characteristics of Active Cyclists

Social-Eco	Surabaya City	%
Age	15-25 Years	43,0
Gender	Man	63,0
Education	Student/Student	35,0
Income	3 Million – 4 Million	39,0
Work	Student/Student	34,0

source: processed data

The socio-economic characteristics of bicycle users in Surabaya indicate that young people, particularly school and college students, are the dominant users. Bicycle users are predominantly male, reflecting their high mobility and resilience in navigating urban traffic conditions. Based on education and occupation, the majority are school or college students, who consider bicycles an economical, practical, and environmentally friendly mode of transportation for their daily activities. In terms of income, bicycle users generally come from the middle-income group, who use bicycles not only for transportation but also for recreation and a healthy lifestyle. Overall, these findings indicate that cycling in Surabaya has become part of the mobility patterns of urban communities, especially among young people, and therefore needs to be supported by the provision of transportation infrastructure and policies that prioritize safety and sustainability.

b. Behavioral Characteristics

Table 3. Behavioral Characteristics of Active Cyclists

Focus Examination	Surabaya City	Percentage
Memeriksa kondisi lampu sepeda	Never	81,0%
Checking the condition of the bicycle brakes	Always	65,0%
Checking the condition of the bicycle tires	Always	79,0%
Checking the condition of the bike chain	Always	60,0%
Wearing a helmet	Never	79,0%
Wearing gloves	Never	77,0%
Wearing knee protection	Never	92,0%
Wearing elbow protection	Never	93,0%
Wearing light/brightly colored clothing	Never	44,0%
Riding together	Never	74,0%
Walking in a group	Never	65,0%
Jokes	Never	81,0%
Breaking through the red light	Never	91,0%
Carrying large quantities of goods/cargo	Never	92,0%
Ahead of other vehicles from the right	Never	74,0%
Marking when to turn right	Always	65,0%
Traveling by bike in the rain	Never	57,0%

source: processed data

Based on the results of a survey of the behavior and habits of bicycle users in Surabaya, it appears that the majority of cyclists have a fairly good awareness of checking the technical condition of their bicycles, such as brakes, tires, and chains, before use. This indicates an effort to maintain safe riding, particularly in terms of vehicle roadworthiness. However, awareness of personal safety equipment remains low, as evidenced by the infrequent or even never use of protective equipment such as helmets, gloves, knee pads, and elbow pads. Furthermore, most cyclists also demonstrate orderly traffic behavior, such as not running red lights, not carrying passengers, and signaling when turning. Nevertheless, increased education is needed regarding the importance of using personal safety equipment, especially given the high risk of road accidents. Overall, these results reflect that cyclists in Surabaya are relatively orderly in traffic, but there is still a need for improvement in awareness of personal safety and the use of protective equipment while riding.

c. Characteristics of Bicycle Equipment

Table 4. Characteristics of Bicycle Equipment

No	Examination	Surabaya City	%
1	Rem	Complete	99
2	Headlights	Incomplete	68
3	Taillights	Incomplete	53
4	Bel	Incomplete	51
5	Squirt	Complete	51
6	Basket	Incomplete	63
7	Fender	Complete	68
8	Chain closure	Incomplete	58
9	Bicycle standard	Complete	85

source: processed data

Based on the results of an inspection of bicycle component completeness in Surabaya, it was found that most cyclists had bicycles in fairly good condition in terms of basic functionality, particularly brakes and kickstands, which were largely complete. This indicates that cyclists pay sufficient attention to basic safety aspects directly related to control and balance while riding. However, many bicycles are still not equipped with supporting safety components such as headlights, taillights, bells, and chain covers. This condition indicates that visibility and additional safety for cyclists are not yet a top priority. Furthermore, accessories such as baskets and pillion seats vary, likely tailored to individual user needs. Overall, these findings indicate that although cyclists in Surabaya have paid attention to the basic functionalities of bicycles, there is still a need to increase awareness of the importance of complete safety accessories to support safety and comfort while riding, particularly in dense urban traffic environments.

d. Movement Characteristics

Table 5. Movement Characteristics

Movement	Surabaya City	%
Purpose and Purpose	Olahraga	30
Start Activities	04:00 - 06:00	55
Mileage	< 5 KM	37
Travel Time	< 30 Minutes	72
User Intensity	Indeterminate	32

source: processed data

Survey results indicate that bicycle use in Surabaya is predominantly for exercise, with the highest frequency occurring in the morning between 4:00 and 6:00 a.m. Most cyclists travel less than five kilometers in less than thirty minutes, indicating that cycling is primarily recreational and short-distance. The inconsistent frequency of use indicates that cycling has not yet become a regular habit, but rather a health and recreational activity.

e. Accident Characteristics

Table 6. Accident Characteristics

Accident	Surabaya City	%
Victim's Condition	Minor Wounds	77
Scene of Incident	Straight ahead	52
Types of collisions	Sides and Back	50
Causal Factors	Your own fault	31
Time of Occurrence	Morning	81

source: processed data

Data on cyclist accidents in Surabaya shows that most victims suffered minor injuries, with the majority of incidents occurring on straight roads. The most frequent types of collisions were side-on and rear-end collisions, indicating a lack of vigilance on the part of both cyclists and other road users in maintaining a safe following distance. The primary cause of these accidents generally stems from cyclist error, such as carelessness or failure to comply with traffic regulations. Furthermore, most accidents occurred in the morning, when traffic activity increases. These findings highlight the need to increase safety awareness and provide safer facilities for cyclists in Surabaya.

f. Geometric and Traffic Characteristics

Table 7. Geometric and Traffic Characteristics

Street Name	Road Function	Road Type	Number of Columns	Direction	Column Width (m)	Road Shoulder (m)	Total Volume (SMP/Hour)	Speed (km/h)
Ahmad Yani	Arteri Primer	6/2 D	3	To the North	9,35	1 (hardened)	9743,00	20,94
			3	To the South	9,35	1 (hardened)		
Darmo	Artery Seconds	6/2 D	3	To the North	11,5	1 (hardened)	3192,00	25,60
			3	To the South	11,5	1 (hardened)		
Ir. H. Soekarno	Primer Collector	6/2 D	3	To the North	9,7	-	3284,15	55,88
			3	To the South	10	-		
Kedung Cowek	Primer Collector	6/2 D	3	To the West	13,8	-	3270,00	27,50
			3	To the East	14,2	-		
Kenjeran	Artery Seconds	6/2 D	3	To the West	9,7	0,5 (hardened)	2434,90	20,20
			3	To the East	9,6	0,5 (hardened)		
Mastrip	Secondary Collector	2/2 UD	1	To the North	6,25	1,5 (hardened)	1284,00	48,56
			1	To the South		1,5 (hardened)		
Ngagel	Arteri Primer	2/2 UD	1	To the North	6	0,5 (hardened)	2476,12	33,95
			1	To the South	6	0,5 (hardened)		

source: processed data

Based on geometric data and traffic characteristics of several roads in Surabaya, it can be concluded that road conditions vary according to their function and level of service.

Jalan Ahmad Yani and Jalan Ngagel, which function as primary arteries, experience high traffic volumes, particularly in the northbound direction, with relatively low average speeds due to high vehicle density. Meanwhile, Jalan Darmo and Jalan Kenjeran, which function as secondary arteries, exhibit moderate traffic volumes with limited vehicle speeds due to the high urban activity in the surrounding area. In contrast, Jalan Ir. H. Soekarno, as a primary collector road, has the highest traffic flow speed among other roads, indicating a good level of smoothness despite the relatively high vehicle volume. Jalan Kedung Cowek and Jalan Mastrip, which function as collectors, exhibit smoother traffic conditions with higher average speeds than arterial roads. Overall, these data illustrate that differences in road function and geometric characteristics influence traffic volume and speed, which are important considerations in bicycle lane planning to ensure cyclist safety and comfort on all road types.

g. Design of Dedicated Bicycle Lanes in Surabaya

Based on the characteristics of Surabaya's traffic, which is dominated by high motorized vehicle volumes and varying traffic speeds on each road function, designing dedicated bicycle lanes is an urgent need to improve cyclist safety and comfort.

Table 8. Road Characteristics and Traffic Flow in Surabaya

Street Name	Road Function	Road Type	Direction	Column Width (m)	Road Shoulder (m)	Volume Total (SMP/Hour)	Speed (km/h)	Capacity (SMP/Hour)	VCR	LOS
Ahmad Yani	Arteri	6/2 D	North	9.35	1 (hardened)	9743.00	20.94	9702.00	1.00	**E**
			South	9.35	1 (hardened)					
Darmo	Arteri	6/2 D	North	11.5	1 (hardened)	3192.00	25.60	3132.00	1.02	**F**
			South	11.5	1 (hardened)					
Ir. H. Soekarno	Collector	6/2 D	North	9.70	-	3284.15	55.88	9504.00	0.35	**B**
			South	10.00	-					
Kedung Cowek	Collector	6/2 D	West	13.80	-	3270.00	27.50	10692.00	0.31	**B**
			East	14.20	-					
Kenjeran	Arteri	6/2 D	West	9.70	0,5 (hardened)	2434.90	20.20	9694.08	0.25	**B**
			East	9.60	0,5 (hardened)					
Mastrip	Collector	2/2 UD	North	6.25	1,5 (hardened)	1284.00	48.56	2589.70	0.50	**C**
			South	6.25	1,5 (hardened)					
Ngagel	Arteri	2/2 UD	North	6.00	0,5 (hardened)	2476.12	33.95	2245.47	1.10	**F**
			South	6.00	0,5 (hardened)					

source: processed data

It is known that the traffic flow in Surabaya City, namely Jalan Ir. H. Suekarno, Jalan Kedung Cowek, and Jalan Kenjeran has a Volume Capacity Ratio of 0.35; 0.31 and 0.25 where based on Table 2.8 regarding the level of service of the entrance to LOS B which indicates that the flow is stable, not free (good traffic flow, possible slowdowns), operating speeds are starting to be limited, and there are obstacles from other vehicles. Jalan Raya Mastrip has a Volume Capacity Ratio of 0.50 based on Table 2.8 regarding the level of service of the entrance to LOS C which indicates that the flow is stable, limited speed (traffic flow is still good and stable with acceptable slowdowns), obstacles from other vehicles are getting bigger. Jalan Ahmad Yani has a VCR value of 0.90 and 0.83 where based on Table 2.8 regarding the level of service of the entrance to LOS E which indicates that the flow is unstable, sometimes experiencing congestion (vehicle volume is at capacity, unstable flow). Meanwhile, Jalan Darmo and Jalan Ngagel have VCR values of 1.02 and 1.10, respectively. Table 2.8 shows that road service levels fall into the LOS F category, indicating congestion and long queues (service volume exceeds capacity, and traffic congestion is present). The geometric characteristics of the roads involved in cyclist accidents in Surabaya are 2/2 UD, as seen on Jalan Mastrip and Jalan Ngagel, while the other selected roads are 6/2D.

h. Selection of Bicycle Lane Design Type

The selection of the bicycle lane design type is based on the similarity of the geometric characteristics of the selected roads without considering their structural features.

Table 9. Planned Bicycle Lane Design Type

Street Name	Road Function	Road Type	Direction	Lane Width (m)	Road Shoulder (m)	LOS	Bicycle Lane Planning Module	Design Type Plan
Ahmad Yani	Arteries	6/2 D	North	9.35	1 (hardened)	**E**	A/B	Type C (road bike)
			South	9.35	1 (hardened)			
Darmo	Arteries	6/2 D	North	11.5	1 (hardened)	**F**	A/B	Type C (road bike)
			South	11.5	1 (hardened)			
Ir. H. Soekarno	Collector	6/2 D	North	9.70	-	**B**	A B C	Type A (bike lane)
			South	10.00	-			
Kedung Cowek	Collector	6/2 D	West	13.80	-	**B**	A B C	Type A (bike lane)
			East	14.20	-			
Kenjeran	Arteries	6/2 D	West	9.70	0.5 (hardened)	**B**	A/B	Type A (bike lane)
			East	9.60	0.5 (hardened)			
Mastrip	Collector	2/2 UD	North	6.25	1.5 (hardened)	**C**	A B C	Type A (bike lane)
			South	6.25	1.5 (hardened)			
Ngagel	Arteries	2/2 UD	North	6.00	0.5 (hardened)	**F**	A/B	Type C (road bike)
			South	6.00	0.5 (hardened)			

source: processed data

The selection of special bicycle lane designs in Surabaya City uses Type A (bike lane) and Type C (bike road). The absence of Type B (bike path) on selected road sections in Surabaya City is due to the insufficient width of the sidewalk when combined with a special bicycle lane, so it is feared that there will be a conflict between cyclists and pedestrians. The road sections with the planned bike lane design type include Jalan Ir. Suekarno, Jalan Kedung Cowek, and Jalan Kenjeran because on these road sections the road width is considered sufficient if combined with a special bicycle lane without disturbing other vehicle lanes and has a LOS between the AC ranges. The selection of the bike lane type is basically intended for traffic with relatively high vehicle speeds, in addition to providing protection also to provide ease of mobility for cyclists, the characteristics of bicycles are different from the characteristics of motorized vehicles so that they require higher security. Meanwhile, the planned bike road design type is Jalan Ahmad Yani, Jalan Darmo, Jalan Ngagel and Jalan Mastrip because these roads have narrow shoulder and road widths and have LOS ≥C so that it is not possible to use Type A or Type B. Type C bicycle users are prioritized for bicycle users who already have experience because they have to share the road with other vehicles without any signs or markings that separate them.

CONCLUSION

Bicycle accidents in Surabaya City are primarily influenced by socio-economic, behavioral, equipment-related, movement, and geometric traffic factors. Most accidents involve young cyclists with low safety awareness who often neglect protective gear and ride poorly equipped bicycles lacking lights or bells, reducing visibility. These incidents predominantly occur on straight roads in the morning when alertness is low and motorized traffic is dense, worsened by the absence of adequate bicycle lanes. The analysis of road characteristics and level of service (LOS) shows that bicycle lane design should correspond to road function and traffic performance—Type C (bike road) with physical separation is suitable for high-volume arterial roads with low LOS (E–F), such as Ahmad Yani, Darmo, and Ngagel, while Type A (bike lane) without full separation fits collector roads with better LOS (B–C), like Ir. H. Soekarno, Kedung Cowek, and Mastrip. These measures aim to enhance safety while maintaining smooth traffic flow. Future research should explore cyclist behavior under different infrastructure designs and evaluate safety outcomes post-implementation to guide data-driven policy and infrastructure improvements.

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