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Urban Land Use and Road Safety in a City Under Pressure: Spatial Evidence from Central Surabaya, Indonesia

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Abstract: Rapid urban development and increasing mobility demand have intensified road safety challenges in city centers. This study examines the relationship between urban land use and road safety in Central Surabaya, Indonesia, using Geographic Information Systems (GIS) and Kernel Density Estimation (KDE). The analysis utilized 2023 land-use data and 351 traffic crash records from 2019–2023 obtained from the Integrated Road Safety Management System (IRSMS). The results reveal that traffic crashes are strongly concentrated within commercial and service corridors characterized by high activity intensity and accessibility. Major crash hotspots were identified in Dr. Soetomo, Embong Kaliasin, Keputran, and Genteng, while fatality hotspots were primarily concentrated in Dr. Soetomo and Embong Kaliasin. A total of 45 fatalities were recorded, and pedestrian-related crashes accounted for 11.4% of all incidents. The findings indicate that crash occurrence is closely associated with mobility conflicts, particularly at intersections, turning movements, and pedestrian crossing locations. The spatial overlap between commercial land uses and crash hotspots highlights the influence of urban activity concentration on road safety risks. The study emphasizes the need to integrate road safety considerations into land-use planning and sustainable mobility strategies to support safer and more inclusive urban environments.

Keywords: urban land use; road safety; traffic crash hotspots; kernel density estimation (KDE); active mobility

1. Introduction

Urbanization has accelerated the transformation of land use in cities worldwide, particularly in urban cores where economic activities, population concentration, and mobility demand continue to intensify. While urban densification may improve accessibility and economic productivity, it also generates increasing pressure on transportation systems and road safety performance (Banister, 2018; Holden et al., 2017). The World Health Organization (WHO, 2023) estimates that road traffic injuries remain one of the leading causes of death globally, with urban areas experiencing disproportionately high exposure to traffic conflicts due to concentrated travel demand and complex interactions among road users. Consequently, road safety is increasingly recognized not only as a transportation issue but also as a challenge closely linked to urban spatial development and land-use dynamics.

A growing body of literature demonstrates that land-use characteristics influence traffic volumes, travel behavior, accessibility patterns, and ultimately road safety outcomes. Commercial, mixed-use, and high-density developments tend to generate greater trip attraction and increase interactions among vehicles, pedestrians, cyclists, and public transport users (Ewing & Cervero, 2010; Xie et al., 2019). Beyond their transportation implications, intensive urban land uses also shape infrastructure demand and investment needs, reflecting the broader relationship between urban development and infrastructure provision (Rahadyan & Wibowo, 2025).

Studies in China, Europe, and North America have found that areas with intensive commercial activities frequently experience higher crash frequencies due to increased turning movements, curbside activities, access points, and modal conflicts (Christiansen et al., 2017; Wang & Noland, 2021). These findings suggest that road safety risks are often embedded within the spatial structure of cities rather than randomly distributed across urban space.

The relationship between land-use intensification and road safety is particularly important in developing countries, where rapid urban growth often outpaces the provision of safe transport infrastructure and effective traffic management (Ministry of Transportation of Indonesia, 2023). In many Southeast Asian cities, including Indonesia, commercial expansion, mixed traffic conditions, motorcycle dominance, and inadequate pedestrian facilities create environments characterized by elevated crash risks and greater vulnerability among non-motorized users (Susilo et al., 2019; WHO, 2023). Previous studies have highlighted that urban corridors experiencing rapid functional transformation frequently become locations of recurring traffic conflicts, especially where accessibility improvements are not accompanied by road safety interventions (Tan et al., 2020; Wang & Noland, 2021).

Surabaya, Indonesia's second-largest metropolitan area, illustrates these challenges within its central urban districts, where commercial expansion and intensified urban activities have increased mobility demand and traffic interactions. Despite growing attention to sustainable mobility and road safety, empirical studies that explicitly examine the spatial relationship between urban land-use patterns and traffic crash concentrations in Indonesian city centers remain limited. Most existing studies investigate land use and transportation separately, with limited integration of spatial crash analysis and urban land-use characteristics. Therefore, this study aims to analyze the relationship between land-use patterns and road safety in Central Surabaya by integrating Geographic Information System (GIS)-based land-use mapping and Kernel Density Estimation (KDE) of traffic crashes. The findings are expected to contribute to the development of safety-oriented urban planning strategies that better integrate land-use management and sustainable mobility objectives.

2. Literature Review

Urbanization has intensified land-use development in many cities, particularly within urban cores where economic activities, population concentration, and accessibility continue to increase. While urban intensification can improve economic productivity and accessibility, it also generates higher mobility demand and increases pressure on transportation systems (Banister, 2018; Holden et al., 2017). According to the land use-transport interaction framework, land-use patterns influence the distribution of activities and accessibility, which subsequently shape travel demand and movement patterns across urban areas (Giuliano, 1995; Ewing & Cervero, 2010). Consequently, areas characterized by intensive commercial and service activities tend to attract larger traffic volumes and more diverse travel modes than predominantly residential areas.

A growing body of literature suggests that land-use characteristics are closely associated with road safety outcomes. Commercial and mixed-use environments often experience higher crash frequencies because they generate greater traffic exposure, more turning movements, increased curbside activities, and more frequent interactions among vehicles, pedestrians, and cyclists (Xie et al., 2019; Wang & Noland, 2021). Christiansen et al. (2017) further argue that high accessibility and activity concentration can increase crash risks when supporting infrastructure such as pedestrian crossings, sidewalks, and traffic calming measures does not evolve alongside urban development. These findings indicate that traffic crashes are frequently influenced by urban spatial structure rather than being randomly distributed across cities.

Road safety concerns are particularly significant for vulnerable road users (VRUs), including pedestrians and cyclists. In dense urban environments, active mobility users are often exposed to greater risks due to their direct interaction with motorized traffic and their dependence on safe street design. Previous studies have shown that pedestrian crashes are commonly concentrated within commercial corridors and mixed-use districts where crossing activities and multimodal interactions are most intensive (Pucher & Buehler, 2017; ITF, 2022). As a result, road safety is increasingly recognized as a multidimensional urban planning issue that requires integration between transportation management, land-use planning, and urban design (WHO, 2023).

Spatial analysis provides an effective approach for examining the relationship between urban land use and road safety. Among various methods, KDE is widely used to identify crash hotspots by transforming individual crash locations into a continuous density surface (Erdogan et al., 2008; Levine, 2015). KDE enables researchers to visualize areas with elevated crash concentrations and to explore how crash patterns correspond with urban activity centers and land-use characteristics. Consequently, KDE has become one of the most commonly applied techniques in road safety studies seeking to understand the spatial dimensions of traffic risk.

Despite growing evidence on the relationship between land use and road safety, empirical studies that explicitly integrate urban land-use characteristics and spatial crash patterns in Indonesian city centers remain limited. Most previous studies have examined transportation safety and urban development separately, with limited attention to how urban spatial structure influences crash concentration and vulnerable road user risks. Therefore, this study integrates land-use mapping and KDE-based crash analysis to examine how urban land-use patterns shape traffic crash concentration, fatality risks, and active mobility safety in Central Surabaya.

3. Research Methodology

This study adopts a spatial analytical approach to examine the relationship between urban land-use characteristics and road safety in Central Surabaya, Indonesia. The study area covers three central districts, namely Bubutan, Genteng, and Tegalsari, which function as the city's primary commercial, administrative, and service center. Traffic crash data were obtained from the Integrated Road Safety Management System (IRSMS) managed by the Traffic Police Unit of the Surabaya Metropolitan Police (Satlantas Polrestabes Surabaya) and cover the period 2019–2023. The use of a five-year crash dataset was intended to capture persistent spatial patterns and reduce the influence of annual fluctuations in crash occurrence, a common practice in road safety studies seeking to identify stable crash hotspots (Anderson, 2009; Levine, 2015).

Existing land-use data were derived from the Surabaya Land Use Database compiled from the interpretation of LiDAR aerial photography (2016), SPOT 6/7 imagery (2018–2019), Pleiades imagery (2020), GeoEye imagery (2021), and WorldView-3 imagery (2021). The multi-year remote sensing data was verified and updated to represent the 2023 baseline through minor field checks or local development plans. The integration of multi-source remote sensing data enables a more comprehensive representation of the urban spatial structure and activity distribution within Central Surabaya. The analysis was conducted using GIS to investigate the spatial relationship between land-use patterns and traffic crashes. Traffic crash locations were geocoded and mapped to examine their spatial distribution across the study area. Descriptive analyses were subsequently performed to assess crash characteristics, including crash type, road function, road geometry, time of occurrence, fatalities, and active mobility crashes involving pedestrians and cyclists. GIS-based approaches have been widely employed in transportation safety research because they facilitate the integration of spatial, environmental, and transportation datasets within a single analytical framework (Erdogan et al., 2008; Levine, 2015).

To identify crash hotspots, KDE was applied to the crash dataset. KDE transforms individual crash locations into a continuous density surface, allowing the visualization of areas with elevated crash concentrations and the identification of spatial risk patterns (Silverman, 1986; Erdogan et al., 2008). Compared with simple point mapping, KDE provides a more effective representation of crash clustering and has become one of the most widely used techniques in traffic safety studies (Anderson, 2009; Levine, 2015). The KDE density value is calculated as follows:

$$f(x) = \frac{1}{nh}\sum_{i=1}^{n} K\left(\frac{x - x_i}{h}\right)$$

where $f(x)$is the estimated crash density at location x, $x_i$denotes the location of an individual crash, $h$is the bandwidth (search radius), and Krepresents the kernel function. The resulting density surfaces were subsequently overlaid with land-use data to examine the spatial relationship between urban activity concentration, crash occurrence, fatality hotspots, and vulnerable road user risks in Central Surabaya.

4. Results and Discussion

4.1. Urban Land Use Characteristics and Traffic Crash Distribution

Central Surabaya is characterized by a highly urbanized land-use structure dominated by commercial and service activities, which occupy 46.3% of the study area, followed by residential land uses accounting for 42.8%. This composition reflects the area's role as the city's primary economic and administrative center, where commercial establishments, offices, public facilities, and residential functions coexist within a relatively compact urban environment. According to land use-transport interaction theory, such concentrations of urban activities generate substantial travel demand and increase traffic exposure (Giuliano, 1995; Ewing & Cervero, 2010).

The spatial distribution of crash locations reveals a clear tendency to cluster within commercial and service corridors, particularly in Genteng, Embong Kaliasin, Ketabang, and surrounding activity centers. These areas function simultaneously as destinations, access corridors, and through-movement routes, creating intensive interactions among vehicles, pedestrians, and other road users. Figure 1 demonstrates that crash locations are not randomly distributed but are concentrated within areas characterized by high levels of accessibility and economic activity.

Table 1 Land Use Composition in Central Surabaya

Land Use Category	Area (ha)	Percentage (%)
Commercial and Service Areas	571.32	46.3
Residential Areas	527.44	42.8
Road Network	85.43	6.9
Urban Forests, Green Corridors, and City Parks	22.63	1.8
River	19.67	1.6
Railway	6.29	0.5
Drainage Canal	0.83	0.0
Shrubland	0.01	0.0
Total	**1,233.61**	**100.0**

The observed pattern supports previous findings that commercial and mixed-use environments tend to experience elevated crash frequencies due to greater traffic volumes, frequent turning movements, roadside activities, and increased modal interactions. In contrast, areas dominated by residential land uses and urban green spaces generally exhibit lower crash concentrations despite occupying a substantial proportion of the study area. This suggests that road safety risks are influenced more by activity intensity and mobility exposure than by land-use extent alone.

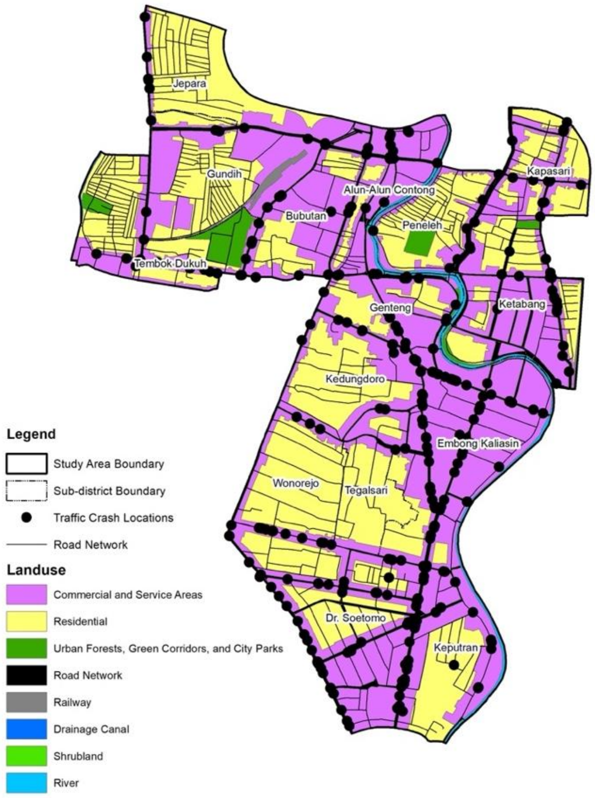


Figure 1 Existing Land Use (2023) and Traffic Crash Locations (2019–2023) in Central Surabaya

The spatial overlap between commercial land uses and crash locations indicates that traffic crashes in Central Surabaya are closely associated with the concentration of urban activities. As commercial districts continue to function as major trip attractors, mobility conflicts become increasingly embedded within the urban environment. Consequently, road safety challenges should be understood not only as transportation issues but also as outcomes of urban spatial structure and land-use organization, providing a foundation for the hotspot analysis presented in the following section.

4.2. Spatial Concentration of Traffic Crash Hotspots and Mobility Conflicts

KDE analysis indicates that traffic crashes in Central Surabaya are spatially concentrated rather than randomly distributed across the urban area. Between 2019 and 2023, a total of 351 crashes were recorded, with several prominent hotspots emerging in the southern and southeastern parts of the study area. The highest crash densities are observed around Dr. Soetomo, Embong Kaliasin, Keputran, and parts of Genteng, suggesting that crash occurrence is closely associated with corridors characterized by high accessibility and intensive urban activities. Previous studies have shown that highly accessible urban environments tend to generate greater traffic exposure due to the concentration of travel demand, resulting in elevated crash frequencies (Ewing & Cervero, 2010; Pulugurtha et al., 2013).

The hotspot pattern is consistent with the administrative distribution of crashes across the study area. Tegalsari District recorded the highest number of crashes (162 incidents; 46.2%), followed by Genteng (124 incidents; 35.3%) and Bubutan (65 incidents; 18.5%). At the urban village level, Dr. Soetomo (79 crashes), Embong Kaliasin (54 crashes), Tegalsari (39 crashes), and Keputran (31 crashes) emerged as the most affected locations. These areas function as major commercial, service, and institutional centers that attract substantial daily travel demand and generate intensive interactions among road users.

Table 2 Distribution of Traffic Crashes by District and Urban Village (2019–2023)

District and Sub District	Number of Crashes
Bubutan	**65**
Alun-alun Contong	16
Bubutan	20
Gundih	8
Jepara	5
Tembok Dukuh	16
Genteng	**124**
Embong Kaliasin	54
Genteng	26
Kapasari	12
Ketabang	26
Peneleh	6
Tegalsari	**162**
DR. Soetomo	79
Kedungdoro	13
Keputran	31
Tegalsari	39
Grand Total	**351**

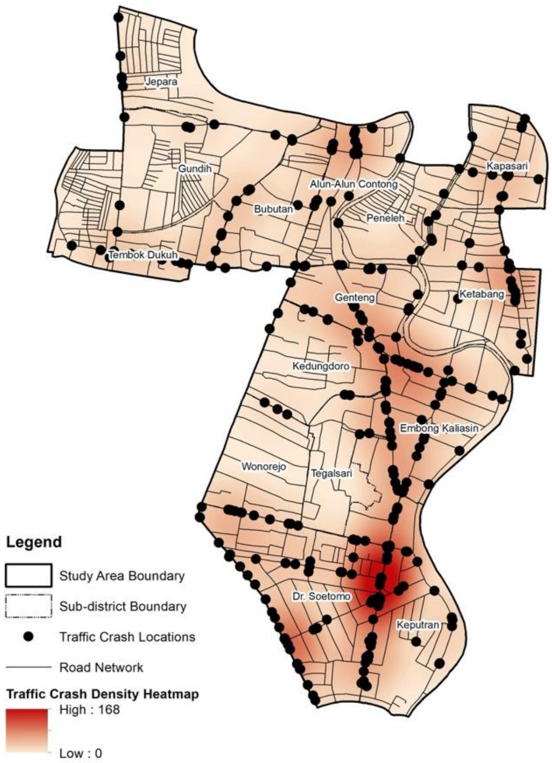


Figure 2 Traffic Crash Density Heatmap (2019–2023) in Central Surabaya

The temporal distribution of crashes further reflects the influence of urban activity patterns. The highest number of crashes occurred during the midday period (10:00–14:00), accounting for 87 incidents, followed by the afternoon period (14:00–18:00) with 70 incidents. Unlike many cities where crashes peak primarily during commuting periods, Central Surabaya exhibits elevated crash frequencies throughout the day, reflecting its role as a multifunctional urban center where commercial, administrative, educational, and service activities continuously generate traffic movements. Similar patterns have been identified in dense mixed-use urban environments where travel demand remains consistently high beyond conventional peak hours (Banister, 2018).

Table 3 Temporal Distribution of Traffic Crashes and Dominant Contributing Factors

Period	Time Range	Number of Crashes	Dominant Contributing Factors Based on Crash Descriptions
Early Morning	00:00–06:00	52	Crashes were primarily associated with driver inattention, reduced concentration, fatigue, and lower traffic volumes that encouraged riskier driving behavior.
Morning	06:00–10:00	61	Many crashes resulted from unsafe lane-changing maneuvers, turning conflicts, and increased traffic demand associated with commuting trips to workplaces and schools.

Period	Time Range	Number of Crashes	Dominant Contributing Factors Based on Crash Descriptions
Midday	10:00–14:00	87	This period recorded the highest number of crashes. The dominant factors included unsafe turning movements, driver inattention, and inadequate following distances in areas characterized by intense commercial and service activities.
Afternoon	14:00–18:00	70	Traffic conflicts were largely driven by frequent access movements, lane-changing behavior, and interactions at intersections and commercial access points.
Evening	18:00–22:00	59	The concentration of homebound trips and evening commercial activities contributed to crashes related to driver inattention, insufficient safety distances, and unsafe overtaking maneuvers.
Night	22:00–24:00	22	Crashes during this period were generally associated with reduced driver alertness, lower visibility conditions, and relatively higher travel speeds under lighter traffic conditions.
Total		**351**	

Crash characteristics reveal that mobility conflicts constitute a major source of road safety risk in Central Surabaya. Intersection and turning collisions account for 42.5% of all crashes, followed by rear-end collisions (17.1%) and lane-changing or overtaking conflicts (16.8%). These crash types are typically associated with complex traffic environments where multiple travel movements converge within limited roadway space. Such conditions are common in dense urban centers where accessibility functions and mobility functions overlap, increasing opportunities for vehicle conflicts (AASHTO, 2018; ITF, 2022).

Table 4 Crash Type Distribution (351 crashes)

Main Crash Type	Frequency	Percentage (%)
Intersection / Turning Collisions	149	42.5
Rear-End Collisions	60	17.1
Lane Change & Overtaking Collisions	59	16.8
Pedestrian-Involved Crashes	40	11.4
Side-Swipe / Lateral Collisions	18	5.1
Head-On Collisions	16	4.6
Fixed Object / Parked Vehicle / Railway Collisions	9	2.6
Total	351	100.0

Road environment characteristics further reinforce the observed hotspot patterns. Approximately 75.8% of crashes occurred on collector roads, while 21.4% occurred on arterial roads. In terms of road geometry, straight road segments accounted for 70.4% of crashes, followed by four-leg intersections (18.8%) and T-intersections (8.3%). These findings indicate that crashes are concentrated along corridors that simultaneously perform mobility and accessibility functions, serving both through traffic and local access activities. Consequently, frequent turning movements, lane changes, and roadside interactions increase the likelihood of traffic conflicts.

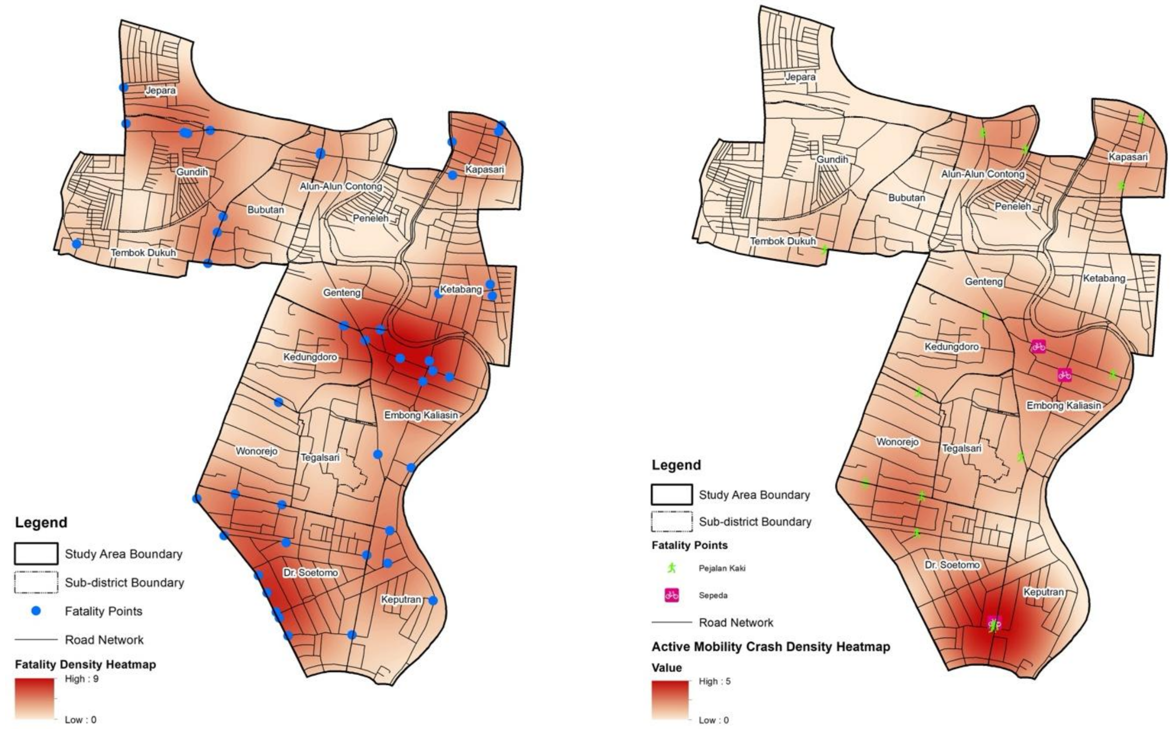
Table 5 Road Environment Characteristics of Traffic Crashes (2019–2023)

Variable	Category	Frequency	Percentage (%)
Road Function	Arterial Road	75	21.4
	Collector Road	266	75.8
	Local Road	10	2.8
Road Geometry	Straight Segment	247	70.4
	Four-Leg Intersection	66	18.8
	T-Intersection	29	8.3
	Curve	4	1.1
	Roundabout	1	0.3
	Bridge	2	0.6
	Other	2	0.6

Overall, the KDE results demonstrate that crash occurrence in Central Surabaya is strongly influenced by spatial concentrations of urban activities and mobility demand. The clustering of crashes within commercial corridors, collector roads, and major activity centers suggests that traffic conflicts are structurally embedded within the urban mobility system rather than randomly distributed across the city. The spatial overlap between crash hotspots and commercial-service areas indicates that traffic conflicts are strongly associated with activity concentration. Commercial corridors in Genteng, Embong Kaliasin, Dr. Soetomo, and Ketabang function simultaneously as destinations, access corridors, and through-movement routes. This combination generates intensive turning movements, curbside activities, pedestrian crossings, and modal interactions that increase crash exposure. Therefore, the KDE hotspots observed in Central Surabaya should be interpreted not merely as transportation phenomena but also as manifestations of urban spatial structure and land-use intensity.

4.3. Road Safety Challenges in a City Under Pressure

While the previous section highlighted where crashes are concentrated, crash severity provides a deeper understanding of road safety challenges within Central Surabaya. Between 2019 and 2023, the recorded 351 crashes resulted in 45 fatalities, indicating that road safety problems extend beyond crash frequency to include significant human consequences. Fatal crashes are particularly important because they reveal locations where mobility conflicts produce the most severe outcomes and therefore require priority intervention within the urban transport system.



(a) (b)

Figure 3 (a) Fatality Density Heatmap and (b) Active Mobility Fatality Density Heatmap in Central Surabaya

The KDE analysis of fatal crashes reveals a more concentrated spatial pattern than that observed for overall crashes. Fatality hotspots are predominantly located within Dr. Soetomo and Embong Kaliasin, with secondary clusters appearing in Kapasari, Gundih, Bubutan, and Alun-Alun Contong. These areas correspond to strategic urban corridors that accommodate substantial traffic volumes and connect major commercial, residential, and institutional destinations. Previous studies have shown that crash severity is often associated with higher operating speeds and roadway characteristics (Elvik, 2013; WHO, 2023). However, the present study focuses on the spatial distribution of fatalities and does not directly evaluate vehicle speed or traffic volume.

A particularly important finding concerns the vulnerability of active mobility users. The spatial distribution of pedestrian and cyclist fatalities reveals localized hotspots within Dr. Soetomo, Embong Kaliasin, Kapasari, Ketabang, Tegalsari, and Alun-Alun Contong. These locations coincide with major commercial and service centers where pedestrian crossing activity, public transport access, and multimodal interactions occur frequently. The overlap between activity centers and active mobility fatalities suggests that increasing urban intensity is not always accompanied by adequate protection for vulnerable road users. The characteristics of active mobility crashes further illustrate this vulnerability. Pedestrian-related crashes accounted for 40 incidents (11.4% of all crashes), of which 82.5% occurred while pedestrians were crossing the roadway. Only a small proportion occurred at intersections or while pedestrians were walking along the roadside. The findings are consistent with previous studies indicating that pedestrians and cyclists are disproportionately exposed to severe injury risks due to their physical vulnerability and direct interaction with motorized traffic (Pucher & Buehler, 2017; ITF, 2022; Ministry of Public Works and Housing, 2021; Putra et al., 2025).

Table 6 Fatality and Active Mobility Crash Characteristics

Indicator	Category	Frequency	Percentage (%)
Crash Severity	Fatalities	45	12.8
	Total Crashes	351	100.0
Active Mobility Crashes	Pedestrian Crossing	33	82.5
	Walking/Standing Along Road	6	15.0
	At Intersection	1	2.5
	Total Active Mobility Crashes	40	100.0

The findings collectively indicate that Central Surabaya exhibits the characteristics of a city under pressure, where concentrated economic activities, high mobility demand, and complex traffic interactions generate persistent safety risks. Fatality hotspots and active mobility crash locations are concentrated within the same urban corridors that function as commercial and service centers, suggesting that road safety challenges are closely linked to broader patterns of urban development. In this context, improving safety requires not only traffic engineering interventions but also greater integration between land-use planning, corridor management, and sustainable mobility policies. Consistent with the Safe System approach, fatality reduction requires interventions that address not only crash frequency but also crash severity and human vulnerability (ITF, 2022; WHO, 2023; Ministry of Public Works and Housing, 2021). Embedding road safety considerations into urban planning decisions is essential to ensure that increasing urban intensity does not result in disproportionate risks for vulnerable road users.

4.4. Discussion

The findings demonstrate that road safety risks in Central Surabaya are closely associated with the spatial concentration of urban activities. Commercial areas exhibit higher crash concentrations, while fatality hotspots tend to occur along major urban corridors where crash severity may be influenced by additional factors beyond land-use intensity, such as roadway characteristics and vehicle operating conditions. This pattern supports the land use-transport interaction framework, which suggests that land-use intensity influences mobility demand, traffic exposure, and the frequency of interactions among road users (Giuliano, 1995; Ewing & Cervero, 2010). Rather than being randomly distributed, traffic crashes in Central Surabaya appear to be structurally linked to the organization of urban space and the concentration of economic activities.

The results are consistent with previous studies demonstrating that commercial and mixed-use environments tend to experience elevated crash risks due to higher traffic volumes, increased turning movements, and more complex modal interactions (Xie et al., 2019; Wang & Noland, 2021). Similar findings have been reported in European and Asian cities, where accessibility improvements and activity concentration often increase crash exposure when road safety considerations are not integrated into urban development processes (Christiansen et al., 2017; Tan et al., 2020). The concentration of crashes within commercial corridors in Central Surabaya, therefore, reflects a broader urban phenomenon in which mobility growth and land-use intensification generate increasing pressure on road safety systems.

The study also highlights the vulnerability of active mobility users within dense urban environments. Although pedestrians and cyclists represent a smaller proportion of total crashes, their spatial concentration within commercial districts indicates that the benefits of accessibility and urban vitality may be accompanied by disproportionate safety risks when adequate pedestrian and cycling facilities are lacking. This finding is consistent with the Safe System approach, which emphasizes that road safety should prioritize the protection of vulnerable road users through safer infrastructure, speed management, and context-sensitive street design (OECD/ITF, 2016; WHO, 2023). The dominance of pedestrian crossing crashes further suggests that safety interventions should focus on improving crossing facilities and reducing conflicts between motorized and non-motorized users.

From an urban planning perspective, the findings suggest that road safety should be considered an integral component of land-use planning rather than solely a transportation issue. Areas experiencing intensive commercial and service activities require proactive safety measures to accommodate increasing mobility demand while protecting vulnerable road users. Integrating road safety principles into zoning regulations, corridor development, urban design guidelines, and mobility planning can help reduce crash risks and improve the overall quality of urban environments, particularly through the provision of safer and higher-quality pedestrian facilities in activity-intensive urban corridors (Dwisadana & Widjajanti, 2024). This perspective is consistent with previous studies emphasizing the importance of spatial planning instruments in guiding urban development intensity and managing growth patterns within urban areas (Rahadyan & Iskandar, 2022), while also highlighting the need to integrate road safety considerations into broader urban planning and infrastructure development strategies. Such an approach aligns with contemporary planning paradigms that promote the integration of land use, transportation, and safety objectives to achieve more sustainable, inclusive, and resilient cities (Banister, 2018; ITF, 2022; WHO, 2023).

5. Conclusions

This study examined the relationship between urban land-use characteristics and road safety in Central Surabaya using GIS-based land-use mapping and KDE of traffic crashes. The findings indicate that traffic crashes are strongly concentrated within commercial and service corridors characterized by high activity intensity, accessibility, and mobility demand. Major crash hotspots were identified in Dr. Soetomo, Embong Kaliasin, Keputran, and Genteng, highlighting the close association between urban activity concentration and crash occurrence. The results further reveal that mobility conflicts, particularly at intersections, turning movements, and lane-changing activities, are key contributors to crash frequency. While fatality hotspots were concentrated along major urban corridors, crash severity may also be influenced by roadway characteristics and vehicle operating conditions beyond land-use intensity alone. In addition, pedestrian-related crashes represent a significant road safety concern, particularly in areas where crossing activities frequently interact with motorized traffic.

Overall, the study demonstrates that road safety challenges in Central Surabaya are closely linked to urban spatial structure and the concentration of economic activities. The spatial overlap between commercial land uses, crash hotspots, and active mobility risks underscores the importance of integrating road safety considerations into land-use planning, corridor development, and sustainable mobility policies. Future research should further investigate the quantitative relationship between land-use intensity, traffic exposure, roadway characteristics, and crash severity through the incorporation of traffic volume, speed, and built-environment variables to support more evidence-based urban planning and road safety interventions.

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