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Research Article

INNOVATING SUSTAINABLE MOBILITY: SPATIAL ZONING AND DIGITAL INTEGRATION IN BALI'S HIGH-DENSITY DESTINATIONS

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Abstract
Bali's exponential tourism growth has triggered chronic traffic congestion, exacerbated by a severe imbalance between vehicle volume and road capacity in high-density areas. This study proposes and evaluates the Tourism Mobility Zoning System (TMZS) integrated with digital navigation technology as a systemic spatial solution. A mixed-method approach was employed, utilizing Simple Linear Regression on secondary macro-data (2011-2024) to empirically justify the urgency of mobility interventions, alongside thematic analysis of field observations, document studies, and in-depth interviews in Kuta, Sanur, and Ubud. The findings indicate that TMZS effectively regulates tourist flows by categorizing destinations into four functional zones: Transit-Oriented, Car-Free, Pedestrian, and Limited Transport. Furthermore, the conceptual integration of TMZS with a real-time digital application (ZonaFlow) optimizes parking management and multi-modal transit efficiency. As a theoretical novelty, this research bridges spatial zoning frameworks with digital technology, extending carrying capacity and Transit-Oriented Development (TOD) theories into a novel socio-spatial model tailored for island tourism. Practically, the study urges policymakers to formally adopt TMZS into regional spatial plans, supported by targeted investments in transit hubs and strict law enforcement, thereby facilitating a sustainable transition from private vehicle reliance.

Keywords: Bali, Spatial Planning, Sustainable Transport, Traffic Congestion, Tourism Mobility Zoning System.

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INTRODUCTION

The sustainable tourism approach is a relevant solution (Baloch et al., 2022; Grizane, 2023; Strippoli et al., 2024; Bisht et al., 2025). According to UNWTO, sustainable tourism is a tourism program that preserves the environment by paying attention to the balance between environmental sustainability and economic benefits (Chirieleison & Rizzi, 2020; Grandcourt, 2020; Baloch et al., 2022; Amoiradis et al., 2023; Aydin et al., 2025). Sustainable tourism can enhance memorable experiences for travelers, which ultimately adds to traveler satisfaction. This concept aims to avoid excessive consumption, support nature conservation, respect local traditions, and preserve them. By adopting sustainable tourism, the

negative impact of tourism development can be minimized, respect for local culture increases, respect for community culture increases, and resources such as water, nature, and culture are maintained.

Bali, as a premier tourist destination in Indonesia, faces serious mobility challenges due to the exponential growth of visitors. In 2023, tourist arrivals reached over 15 million, far exceeding the local population of approximately 4.4 million. This surge, coupled with a high reliance on private vehicles by both tourists and residents, has triggered severe traffic congestion in popular tourist areas such as Kuta, Sanur, and Ubud. This issue is rooted in the high volume of vehicles, illegal parking, ineffective road circulation, and the concentration of tourism in the southern region, which exerts excessive pressure on local infrastructure (Putri et al., 2021; Aryasih et al., 2024; Prabawa et al., 2024; Suryadarmawan et al., 2024).

Various efforts have been made by the government and the private sector to address this issue, yet they still face significant limitations. Large-scale infrastructure projects, such as the proposed Bali Urban Subway, require a long realization time and massive funding. On the other hand, existing technical solutions like the Trans Metro Dewata and Kura-Kura Bus are still confronted with complaints regarding congestion, limited routes, and suboptimal service quality (Purwadana & Yasa, 2019; Dwiputranti, 2023; Aryasih et al., 2024; Wardana et al., 2024). Consequently, tourists are turning to ride-hailing services like Gojek for convenience (Dewantara, 2019; Sriastuti et al., 2024), which inadvertently adds to the vehicle volume. Meanwhile, efforts to provide eco-friendly transportation, such as autonomous buses in Nusa Dua, remain in the prototype stage (Dwipayana et al., 2024).

Despite these various technical interventions, there is an explicit research gap in the literature regarding tourist movement management that integrates spatial and social approaches in Bali. Tourism studies in Bali have predominantly focused on physical infrastructure development, transportation fleet provision, and community empowerment, without specifically addressing zoning-based movement management (Westoby et al., 2021; Dolezal & Novelli, 2022; Rosalina et al., 2023). Globally, GIS-based spatial analysis and zoning (such as core-and-buffer zones) have proven effective in managing tourist distribution (Asero et al., 2016; Sugimoto et al., 2019; Tomej & Liburd, 2020), but these approaches are rarely integrated with local socio-cultural aspects (Yiu & Cheung, 2021; Jones et al., 2023). Therefore, a systemic approach that combines spatial planning with the social dynamics of tourist destinations in Bali has not been comprehensively addressed.

To fill this gap in the literature, this study proposes the implementation of the Tourism Mobility Zoning System (TMZS) as an innovative rationale. TMZS is a systemic approach that classifies destination areas into specific mobility zones such as transit zones, pedestrian zones, vehicle-free zones, and restricted access zones. Grounded in the theory of sustainable mobility (Banister, 2008) and the concept of carrying capacity, TMZS regulates tourist mobility to align with the ecological, infrastructural, and social capacity of the area. This spatial management is believed to facilitate more adaptive mobility, alleviate pressure on vulnerable areas (over-tourism), and plan more efficient tourist routes (Asero et al., 2016; Chica et al., 2022).

Based on this rationale, the objective of this research is to examine the potential application of the Tourism Mobility Zoning System (TMZS) as an innovation in Bali's transportation system. Specifically, this study focuses on identifying tourism mobility zones, integrating sustainable transportation modes, and formulating implementation strategies that align with local characteristics. Through this approach, this research seeks to answer how the implementation of TMZS can evenly distribute tourist flows while achieving efficient and sustainable mobility governance.

RESEARCH METHOD

This research uses a multiple case study approach that is exploratory and descriptive in nature. This method is deemed suitable to address the complexities of the dynamics of the tourism transportation system in various destination areas in Bali, particularly in examining the potential application of the Tourism Mobility Zoning System as an innovative solution.

The multiple case study approach enables researchers to conduct an in-depth exploration of the characteristics of tourist mobility, transportation governance, infrastructure capacity, and intermodal integration in various regions with different contexts, yet within one geographic and administrative entity, namely the island of Bali. Multiple case studies provide strength in conducting cross-location comparative analysis, enriching analytical generalizations through both recurring patterns and significant deviations across cases.

The criteria for selecting cases in this study are based on three main considerations relevant to the development goals of the Tourism Mobility Zoning System. First, the selected area is a strategic tourist destination that plays a significant role in the distribution of tourist visits, both domestic and international, making it a central point in the dynamics of Bali's tourism. Second, the area shows a high level of traffic density and often experiences congestion, making it a critical area in the mobility flow of tourists and requiring systemic intervention. Third, the location selection also considers the availability of data and research accessibility, including support from related institutions such as the Department of Transportation, the Department of Tourism, and the Regional Development Planning Agency, which enables optimal data collection.

Based on these three criteria, the research identifies three main tourist destination areas in Bali as case studies, namely the Kuta Area, the Sanur Area, and the Ubud Area. These three areas represent a diversity of geographic, social characteristics, as well as patterns of tourist mobility that are relevant for the development and contextual testing of the Tourism Mobility Zoning System concept. These areas display different mobility characteristics, in terms of spatial planning, attractions, visitor volume, and the complexity of transportation integration. This allows for a comprehensive depiction of the potential and challenges in implementing the Tourism Mobility Zoning System. With this multiple case study, the findings will not only be contextual but also can be developed as best practices for other tourist areas in Bali or similar destinations in Indonesia.

This research also adapts a simple linear regression analysis approach to measure the effect of independent variables (the number of domestic and foreign tourists) on the dependent variable (the number of vehicles) in the province of Bali. The data analyzed comes from official agencies such as the Central Statistics Agency, the Department of Transportation, and the Department of Tourism, covering the period from 2009 to 2019, to ensure trend stability and avoid bias due to anomalies during the pandemic.

Data collection was conducted using a qualitative approach that is exploratory in nature, to delve into a deep understanding of the current tourism transportation system, the challenges of implementing mobility zoning, as well as the perceptions and readiness of stakeholders. The data collection techniques include: 1) Document Study, The document study in this research focuses on examining various policies, regulations, and planning documents directly related to transportation and tourism in Bali. The analyzed documents include the Provincial Master Plan for Tourism in Bali, the Central Bureau of Statistics, and a number of Regional Regulations and Governor Regulations that govern spatial planning and transportation systems; 2) Field Observation were conducted directly in three tourist destination areas that are the case studies in this research, in order to obtain a real picture of the mobility conditions of tourists in the field. The main focus of the observation includes patterns of tourist movement within the areas, identification of congestion points and routes experiencing traffic density, as well as an analysis of the availability of transportation modes such as public transport, hotel shuttles, and ride-hailing services, along with supporting infrastructure such as stops, terminals, and parking areas; 3) In-Depth Interview, in this research were conducted semi-structured with several key informants who have strategic roles in transportation management and tourism development in Bali. The informants included officials from the Tourism Office and Transportation Office at both provincial and district levels, destination managers, tourism transportation entrepreneurs, local community actors or members of the Tourism Awareness Group (Pokdarwis), as well as academics and experts in spatial planning and transportation.

Data analysis in this study integrates qualitative and quantitative approaches. For the qualitative data obtained from document studies, field observations, and in-depth interviews, the analysis was conducted using a thematic approach encompassing data reduction, data display, and conclusion drawing to formulate the strategies of the Tourism Mobility Zoning System (TMZS). For the quantitative analysis, this study employed a Simple Linear Regression test via SPSS on secondary time-series macro-data (2011-2024) sourced from official agencies (BPS, Department of Transportation, and Department of Tourism). Because the analysis relies entirely on secondary data, data validity is inherently guaranteed by the credibility of the issuing institutions.

RESULTS AND DISCUSSION

4.1 General Description of the Case Study Location

The development of transportation in Bali cannot be separated from the growth of tourism since the 1970s. The Kuta area began to be recognized as a beach tourism center after the opening of Ngurah Rai International Airport in 1969. Road infrastructure such as Legian Street and Sunset Road then

developed in line with the influx of tourists, but the growth of vehicles was much faster than the road expansion. The average road width in this area is only about 7 meters, which is not comparable to the increasing volume of vehicles, especially since many vehicles park on the road, narrowing the traffic space.

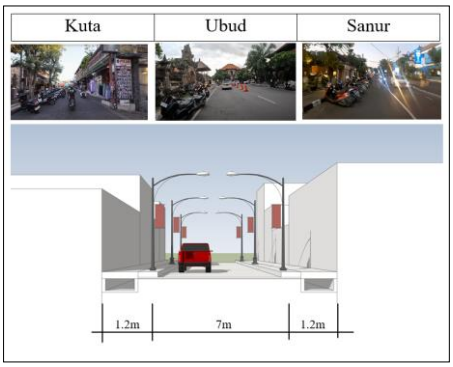

Figure 1. A section of the road in the Bali tourist area (Kuta, Sanur, Ubud) with a width of ±7 m and a sidewalk of 1.2 m, shows the limited capacity of the road against the flow of tourist vehicles.

The use of rented private vehicles by tourists, as is common in Kuta, significantly contributes to the increased traffic burden and congestion in tourist areas and urban environments. Global research shows that the growth of rental and private vehicles significantly exacerbates congestion, reduces average travel speed, and increases external costs such as pollution and travel time (Qian et al., 2020). A similar condition can also be seen in Sanur, which has been known as a tourist destination since the 1930s, especially after Belgian painter Le Mayeur settled in the area. Although it was relatively quiet at first, this area has experienced rapid growth after the opening of fast boat routes to Nusa Penida and Lembongan, leading to a surge in vehicle traffic to the port, which has now become a strategic issue in area management due to congestion, declining environmental quality, and pollution (Qian et al., 2020). Ubud also faces a similar issue; since it rapidly developed in the 1990s as a center for art and culture, the area has limitations in infrastructure with narrow traditional village roads and hilly topography. As the number of visitors has increased, especially after Bali was designated by UNESCO as a world cultural heritage tourism destination, the use of private and rental vehicles has exacerbated mobility and drastically increased traffic load on the routes to popular tourist areas (Qian et al., 2020).

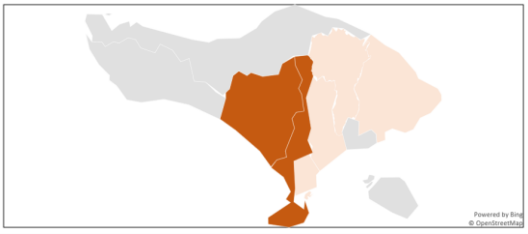

Figure 2. Kuta, Sanur, and Ubud are areas prone to traffic congestion in Bali

According to data from the Bali Provincial Transportation Agency, there are eight main points that are prone to congestion, namely Amed Beach in Karangasem, Sanur Beach–Sanur Port in Denpasar City, the tourist area of Ubud in Gianyar, Kuta and Canggu Beaches in Badung, Tanah Lot and Bedugul in Tabanan, and Kintamani in Bangli. Of all these points, Kuta, Sanur, and Ubud occupy the most crucial positions with distinct congestion characteristics in each area. Kuta often experiences chronic congestion on Jalan Raya Kuta, Legian, and Sunset Road due to illegal parking and a high volume of rental vehicles, with traffic density increasing by up to 40% during holiday seasons (Bali Provincial Transportation Agency). In Sanur, the main issue occurs with access to the fast boat harbor, where travel time during peak hours can double (Atmaja et al., 2024). Meanwhile, in Ubud, traffic congestion is concentrated in the city center such as Monkey Forest, Ubud Market, and Ubud Palace, worsened by large tourist buses getting stuck on narrow village roads, increasing traffic safety risks (Pramudya & Arida, 2016).

The research results show that the main causes of traffic congestion in the tourist areas of Bali can be identified from several factors. First, the growth in the number of private vehicles is occurring much faster than the increase in road capacity, leading to a chronic traffic density due to this imbalance.

Second, the tourism model that relies on rental vehicles encourages every tourist to use their own car or motorcycle, thus significantly increasing road space consumption. Third, the lack of effective public transportation means that both the local community and tourists do not have adequate mobility alternatives, as the existing public transport system has not optimally reached the main destinations. Fourth, the poorly integrated spatial planning with transportation management exacerbates the situation, for example in the Ubud area, where village roads must serve local residents' access, tourist movement, and logistics distribution routes. The last factor that also worsens traffic congestion is the behavior of road users, such as illegal parking and the use of road space by street vendors, which further narrows the traffic lanes.

The solutions for handling traffic congestion in Bali's tourist areas can be divided into short-term, medium-term, and long-term strategies. In the short-term phase, the most realistic steps are traffic engineering through the implementation of a one-way system, restrictions on the operating hours of large buses in downtown Ubud, as well as the organization of centralized parking in crowded areas such as Kuta and Sanur. Research in Makassar shows that addressing parking issues has the most significant impact on reducing traffic congestion compared to other interventions. In the medium term, there is a need for the development of eco-friendly shuttle bus-based public transport that connects the airport with main destinations such as Kuta, Sanur, and Ubud. In the long term, Transit Oriented Development (TOD) strategies are the main choice. This approach emphasizes reducing the use of private vehicles through the development of low-emission mass transit modes, such as electric buses or light rail transit (LRT). This system must be supported by digital technology in the form of route applications and real-time information, which can enhance accessibility while encouraging tourists to shift from private rental vehicles to public transportation. Studies show that route integration and digital support can improve tourist experiences and reduce dependence on private vehicles (Wei et al., 2022). Investment in this mode aligns with Bali's policy direction towards sustainable tourism. Furthermore, it is necessary to educate tourists about the importance of using carpooling, bike sharing, and other environmentally friendly transportation options to reduce traffic pressure and maintain the attractiveness of Bali's tourism.

4.2 Mobility Patterns and Transportation Issues

Each area in Bali has a distinctive pattern of tourist mobility, according to its characteristics and functions. Based on survey results and official data from the Tourism Office and the Transportation Office of Bali Province in 2024, the following presents quantitative data on the number of tourists and vehicles in Bali Province.

Table 1. Number of Tourists and Vehicles in Bali Province

Year	Number of Tourists	Number of Vehicles
2011	8.501.830	2.494.478
2012	9.012.890	2.749.164
2013	10.255.134	3.003.588
2014	10.160.945	3.268.071
2015	11.148.935	3.505.943
2016	13.571.617	3.703.007
2017	14.433.372	3.885.099
2018	15.828.464	4.096.134
2019	16.820.249	4.330.987
2020	5.665.630	4.438.695
2021	4.301.643	4.510.791
2022	10.208.721	4.756.346
2023	15.151.169	5.016.351
2024	16.454.146	5.278.984

Based on Table 1, the number of tourists in Bali Province has shown a significant upward trend over the past decade, increasing from 8.5 million in 2011 to over 16.4 million in 2024. This increase is accompanied by a growth in the number of vehicles, which has nearly risen by three million units during the same period. The surge in visits and vehicles has had a direct impact on mobility patterns in various

major tourist areas, such as Kuta, Sanur, and Ubud, each having distinct characteristics of tourist movement.

In the Kuta area, the movement pattern of tourists is very dense, especially on the main routes to the beach and nightlife centers. Traffic congestion often occurs during peak hours, particularly around the Ngurah Rai By Pass and Legian Street. The dominant mode of transportation is private vehicles and ride-hailing services. Although transportation infrastructure has developed sufficiently, the pressure from the high volume of vehicles remains an issue, especially due to the disproportionate growth of vehicles compared to road capacity and the lack of safe and comfortable pedestrian pathways. In Sanur, the mobility pattern is more dispersed and organized, with tourism activities combining land and sea access. Congestion points tend to concentrate around the port and culinary center. Modes of transportation include hotel shuttles, bicycles, and sightseeing boats. The infrastructure in this area is relatively eco-friendly, but a better digital navigation system and supporting facilities are still needed for tourists. Meanwhile, in Ubud, the mobility of tourists tends to be done by walking or using bicycles, in line with the character of the area that emphasizes cultural and environmental tourism. However, tourist shuttles and private vehicles still contribute to congestion on the main roads. Pedestrian and bicycle paths are still limited, making the development of pedestrian-friendly infrastructure a priority.

Strengthened by the results of regression analysis, it was found that the surge in the number of vehicles is highly correlated with the increase in the number of tourists visiting Bali. The results of simple linear regression analysis show that there is a very strong relationship between the number of tourists (X) and the number of vehicles (Y), which is formulated in the form of a regression equation: **Y = 344.847,588 + 0,248X.** This means that each additional tourist will increase the number of vehicles by 0.248 units. Practically, each increase of one million tourists is estimated to drive an increase of about 248,000 vehicle units on the roads of Bali. The coefficient of determination (R^2) value of 0.921 shows that 92.1% of the variation in the number of vehicles can be explained by the number of tourists. Meanwhile, the remaining 7.9% is influenced by other factors outside the model such as local vehicle ownership, road infrastructure, or transportation policies.

Table 2. Coefficients Number of Tourists (X) Against Number of Vehicles (Y)

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	344847.588	283681.619		1.216	0.255
	X	0.248	0.024	0.960	10.218	0.000

a. Dependent Variable: Y

In addition, the significance test of the model through ANOVA analysis yielded a calculated F value of 104.415 with a significance level of $p = 0.000$ ($p < 0.05$), indicating that this regression model is significant and suitable for predicting the relationship between the number of tourists and the number of vehicles. The regression coefficients are also statistically significant with a t value of 10.218 and $p = 0.000$, indicating that the variable number of tourists has a real effect on the number of vehicles. Thus, tourism activities can be assured as the dominant factor driving the increase in private vehicles in Bali, which ultimately exacerbates congestion, especially in densely populated areas such as Kuta, Sanur, and Ubud. This finding reinforces the urgency of transforming the tourism mobility system to be more adaptive and sustainable.

Therefore, the implementation of the Tourism Mobility Zoning System, the development of public transport that connects different areas, and incentives for environmentally friendly modes of transport are strategic steps that need to be prioritized. Without firm and innovative policy interventions, Bali risks facing stagnation in tourism due to a decline in the quality of the tourist experience, alongside increased pressure on the environmental and social carrying capacity of the area.

4.3 Analysis of the Implementation of the Tourism Mobility Zoning System

The potential implementation of the Tourism Mobility Zoning System in Bali's tourism destinations is very diverse, depending on the characteristics and needs of each area. The Kuta area, as a dense tourism and business center, is very suitable for implementing strict mobility zoning with restrictions on private vehicles and prioritizing eco-friendly transportation such as electric shuttle buses and bicycles. On the other hand, the Ubud area, which emphasizes cultural and ecotourism, is suitable for

zoning that prioritizes pedestrian and bicycle mobility to preserve nature and provide an authentic tourist experience. The Sanur area has high potential for implementing integrated and eco-friendly internal transport-based zoning, such as shuttle systems between hotels. Thus, the implementation of zoning tailored to the characteristics of the area can optimize tourist mobility while also reducing the negative impacts of transportation.

In terms of readiness, the transportation infrastructure in Bali is still uneven. Main areas like Kuta already have adequate road and transportation facilities, but they do not support complex mobility zoning (Budiartha & Joni, 2017). Regulations regarding vehicle restrictions and the development of sustainable transportation have not been fully consistent and harmonious among local governments. Coordination among managing actors, including the government, business actors, and local communities, remains a major challenge. Research by (Nainggolan et al., 2020) emphasizes that synergy among stakeholders is crucial for the success of the tourism mobility zoning system. Therefore, there is a need for stronger regulation and empowerment of managing actors to ensure effective implementation of TMZS.

The principle of the Tourism Mobility Zoning System, which regulates mobility based on zones to reduce congestion and carbon emissions, as well as enhance tourist comfort, is very suitable for the character of the Bali area. The area that highlights nature and cultural tourism is very compatible with zoning that limits motor vehicles and prioritizes sustainable transport modes such as bicycles and electric shuttles. In contrast, urban areas like Denpasar require more flexible zoning while still integrating public transport and digital technology to manage high mobility (Setiawan et al., 2024). With the right adjustments, the Tourism Mobility Zoning System can become an innovative transportation solution that supports sustainable tourism in Bali.

The results of this research show that the implementation of the Tourism Mobility Zoning System is a highly relevant innovation in addressing mobility issues and environmental impacts in tourist areas of Bali. These findings are in line with the theory of sustainable tourism that emphasizes a balance between economic, social, and environmental aspects. Previous studies on mobility zoning in global destinations such as Barcelona and Kyoto indicate that zoning systems can effectively reduce congestion and pollution while enhancing tourist comfort (López et al., 2020; Mueller et al., 2020). This research reinforces that success largely depends on the readiness of infrastructure and integrated policies, as well as the active involvement of stakeholders.

The Tourism Mobility Zoning System is closely related to the concept of sustainable tourism because mobility zoning not only regulates the movement of tourists but also contributes to reducing carbon emissions and preserving the environment (Yiu & Cheung, 2021). By limiting private vehicles and promoting environmentally friendly modes of transportation such as electric vehicles, bicycles, and pedestrian zones, the Tourism Mobility Zoning System aligns with the principles of socially and ecologically responsible tourism management (Gonzalez et al., 2022; Kamar et al., 2024). Furthermore, the involvement of local communities and business actors in managing the zoning ensures the fair and sustainable distribution of social and economic benefits (Gonzalez et al., 2022; Kamar et al., 2024).

Comparing different areas reveals that the success of implementing the Tourism Mobility Zoning System is greatly influenced by local conditions. The Kuta and Ubud areas show high readiness and motivation to implement the Tourism Mobility Zoning System due to the real issues of traffic congestion and environmental degradation. Conversely, the East Bali region, which still has limited infrastructure and regulations, faces various challenges in implementation. Factors such as accessibility, distribution of transportation points, patterns of tourist movement, and the quality of management and destination planning significantly affect the success of the mobility zoning system (Arnold et al., 2023; Sugimoto et al., 2019). Government support, collaboration among stakeholders, and adaptation to local challenges are the main keys to ensure that this system can operate effectively and sustainably (Arnold et al., 2023; Chang & Wu, 2021). On the contrary, the limitations of infrastructure, resistance to restrictions on private vehicles, and suboptimal coordination pose obstacles that must be addressed for the implementation of the Tourism Mobility Zoning System to be widely and effectively applied.

4.4 Tourism Mobility Zoning System Model

4.4.1. Concept of Developing the Tourism Mobility Zoning System Model

The Tourism Mobility Zoning System is an innovative approach that regulates the movement of tourists spatially through the division of specific zones, with the aim of creating efficient, sustainable mobility that aligns with the carrying capacity of the area. This model is in line with the principles of sustainable tourism management, which aims to reduce pressure on the environment, enhance tourist

comfort, and create an inclusive and integrated transportation system. The research emphasizes that the integration of mobility and tourism planning is crucial to address environmental, social, and economic challenges in tourist destinations, as well as to support the achievement of sustainable development goals (SDGs) (Hussain et al., 2023; Myrovali & Morfoulaki, 2025).

The management of mobility through zoning can guide tourists' travel patterns towards a more sustainable direction, for example, by reducing dependence on private motor vehicles and enhancing accessibility to environmentally friendly modes of transport such as public transportation, bicycles, and pedestrians (Hopkins, 2020; Høyer, 2000). Furthermore, restricting tourist density in certain zones has proven to enhance cooperation among local stakeholders and strengthen the sustainability of destinations (Chica et al., 2022). The success of this system is greatly influenced by cross-sector collaboration, continuous monitoring, and adaptation to technological changes and market needs (Hussain et al., 2023; Myrovali & Morfoulaki, 2025). Thus, the Tourism Mobility Zoning System can be a strategic solution for creating more environmentally friendly, equitable, and sustainable tourism. This mobility zoning design is divided into several main zones as follows:

Figure 3. Connectivity Between Tourist Areas

1. Transit-Oriented Zone

Transit zones serve as central points for the transfer of transportation modes from private vehicles to environmentally friendly transport such as electric shuttle buses, bicycles, or pedestrian pathways, and this concept aligns very well with the principles of Transit-Oriented Development (TOD). TOD emphasizes the integration of transportation with spatial planning to minimize the use of private vehicles and encourages the use of public transport and eco-friendly modes (Almatar, 2022; Sung & Eom, 2024). Research in various cities shows that placing transit zones in strategic areas, such as entry gates to major tourist areas, can enhance accessibility, reduce congestion, and support sustainable mobility (Iamtrakul & Chayphong, 2024; Iamtrakul et al., 2025).

Studies in Bangkok and Pathum Thani, for example, found that the concentration of tourism activities and public facilities around transit zones enhances travel efficiency and tourist comfort, especially when supported by an integrated mass transportation network (Iamtrakul et al., 2025; Iamtrakul & Chayphong, 2024). Furthermore, the implementation of TOD has proven to provide economic, social, and environmental benefits, such as reducing travel times, lowering emissions, and improving the quality of life for communities (Almatar, 2022). However, the success of this concept heavily relies on careful planning, infrastructure availability, and collaboration among the government, business actors, and the community (Hasibuan & Mulyani, 2022; Mangu et al., 2025). Thus, integrated transit zones within the TOD framework can be an effective solution for creating a tourism transportation system that is efficient, inclusive, and sustainable. The characteristics of transit zones include: 1) Park and ride facilities (parking places for private vehicles integrated with public transport); 2) Shuttle terminal and bike-sharing services; 3) Easily accessible transportation information for tourists.

2. Car-Free Zone

This zone is an area with strict motor vehicle restrictions, which are generally applied in areas with high conservation value such as tourist villages or sacred sites. The implementation of car-free zones has been proven to be effective in reducing air and noise pollution, as well as supporting the preservation of the environment and culture by decreasing the pressure from motor vehicles. Studies in various cities show that restricting private vehicles in these zones can reduce air pollutant concentrations by up to 40% on certain days, as well as create healthier, safer, and more comfortable public spaces for pedestrians and cultural activities.

In addition to environmental benefits, car-free zones also contribute to the protection of cultural heritage by reducing disturbances to historical sites and sacred areas, as well as improving the quality of life for local communities. However, the success of car-free zones heavily relies on careful planning, alternative transportation support, and community involvement. Challenges such as traffic diversion to surrounding areas and potential social inequality must also be anticipated so that environmental and cultural benefits can be experienced equitably. Features of car-free zones include: 1) The use of non-motorized modes of transportation such as bicycles and walking; 2) Strict access management for special vehicles (logistics, evacuation); 3) Increasing tourist awareness through education and clear signage.

3. Pedestrian Zone

Pedestrian zones in core tourist areas such as Ubud, Seminyak, and other activity centers have proven to provide many benefits, especially in densely populated areas with diverse activities such as shopping centers, cultural attractions, and dining areas. The implementation of pedestrian zones enhances the comfort of tourists, extends their length of stay, and encourages an increase in tourist spending in those areas. Studies in various cities indicate that pedestrianization not only reduces congestion and pollution but also creates a more vibrant, safe, and attractive environment for both tourists and local communities.

In addition, pedestrian zones encourage local economic growth by enhancing social interactions and shopping activities in open spaces, as well as strengthening the identity of tourist areas. The arrangement of sidewalks, bike lanes, and pedestrian-friendly public spaces is crucial to support active and inclusive mobility, as well as to enhance the attractiveness of tourist destinations. However, the success of pedestrian zones greatly depends on careful planning, supporting facilities, and community involvement in the development process. The main feature of pedestrian zones is: 1) Prohibition of motor vehicle entry except for emergency and operational vehicles; 2) Provision of wide, comfortable, and aesthetic pedestrian pathways; 3) Supporting facilities such as seating, parks, and directional signs.

4. Limited Transport Zone

The vehicle restriction zone that only permits certain vehicles such as electric vehicles, official shuttles, and tourism operational vehicles proves to provide various benefits for tourist areas, especially in luxury resort areas like Nusa Dua and Jimbaran. The implementation of this policy can enhance the efficiency and comfort of the tourist environment by reducing air pollution, minimizing congestion, and creating a more exclusive and pleasant atmosphere for tourists. Studies in various cities show that strict restrictions on motor vehicles in tourist zones can significantly reduce pollutant emissions, encourage a shift to environmentally friendly transportation modes, and improve air quality and the environment.

In addition to environmental benefits, this policy can also enhance tourists' positive perceptions of the destination, strengthen the area's image as a premium destination, and support long-term sustainability in tourism. However, the effectiveness of these zones heavily depends on the availability of reliable alternative transportation, community acceptance, as well as consistent oversight and enforcement of regulations. Challenges such as the potential decline in economic activity in restricted areas and the possibility of pollution shifting to surrounding areas must also be anticipated through thorough planning and cross-sector collaboration. Criteria for limited transportation zones: 1) Restrictions on operating hours for motor vehicles; 2) Use of electric and eco-friendly vehicles; 3) Strict supervision by area managers and relevant authorities.

Based on data on the number of tourists and vehicles in Bali Province from 2011 to 2024, there is a noticeable trend of significant increase. This growth, while positively impacting the regional economy, simultaneously presents serious challenges to infrastructure capacity, mobility smoothness, and the environmental quality of the destinations. The increase in traffic congestion in main tourist areas such as Kuta, Sanur, and Ubud has become one of the crucial issues that requires transportation policy interventions.

In this context, the implementation of the Tourism Mobility Zoning System as illustrated in the map above becomes an important strategy for managing tourist flows while also reducing traffic pressure in core tourist areas. The transit zones at the entrances of Kuta, Sanur, and Ubud serve as transfer hubs from private vehicles to environmentally friendly transportation, thereby reducing the volume of motor vehicles entering bustling centers. Furthermore, the implementation of motor vehicle-free zones and pedestrian zones at strategic points helps to curb air pollution and noise, while enhancing the quality of the tourist experience. Meanwhile, limited transportation zones ensure that only certain modes can operate

in sensitive and exclusive areas, maintaining comfort and environmental preservation. Thus, this zoning concept not only serves as a mobility management solution but also as an important instrument in supporting sustainable tourism development in Bali.

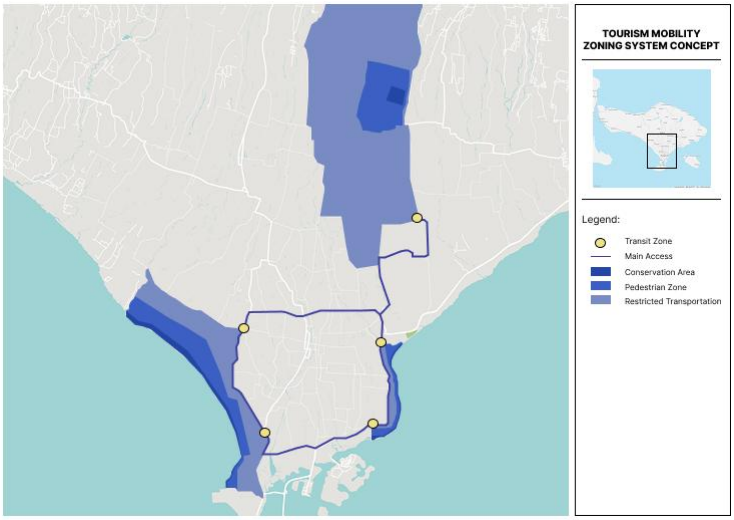

Figure 4. Concept of the Tourism Mobility Zoning System

4.4.2. Digital Design and Technology Integration Through ZonaFlow

ZonaFlow is a travel navigation application designed to help tourists in Bali avoid traffic jams and find parking locations and more efficient travel routes. This application utilizes a Tourism Mobility Zoning System approach by integrating tourism mobility zoning information, traffic camera data, and an interconnected parking recommendation system. The initial interface of the application presents a typical Balinese visual, accompanied by an invitation to explore hidden destinations. After logging in, users are presented with a list of nearby parking spots complete with estimated distance, travel time, and zone indicators. Furthermore, an interactive map with integrated surveillance cameras visually displays the current traffic conditions.

As shown in the figure, users can see the classification of tourism mobility zones such as Conservation Area, Pedestrian Zone, Limited Transport, and Transit Zone marked with different colors. Users can adjust their travel plans according to the applicable zones, as well as use the interactive navigation feature to determine parking locations, departure points, and receive direction guidance based on real-time traffic situations.

Figure 5. The ZonaFlow Application

More than just a parking search, ZonaFlow also offers features for reserving parking spaces according to the mode of transportation used, such as shuttle buses, private vehicles, and scooters. Users can select the date and duration of parking, as well as view an estimated cost that is calculated

automatically. The payment process can be completed through various methods such as PayPal, Google Pay, Apple Pay, or credit cards. After confirmation, the system will display navigation to the selected parking location, followed by arrival confirmation and QR code scanning for parking access. Next, the Parking Timer feature will activate, displaying the remaining parking time, location, type of vehicle, and parking number, as well as providing an option to extend time.

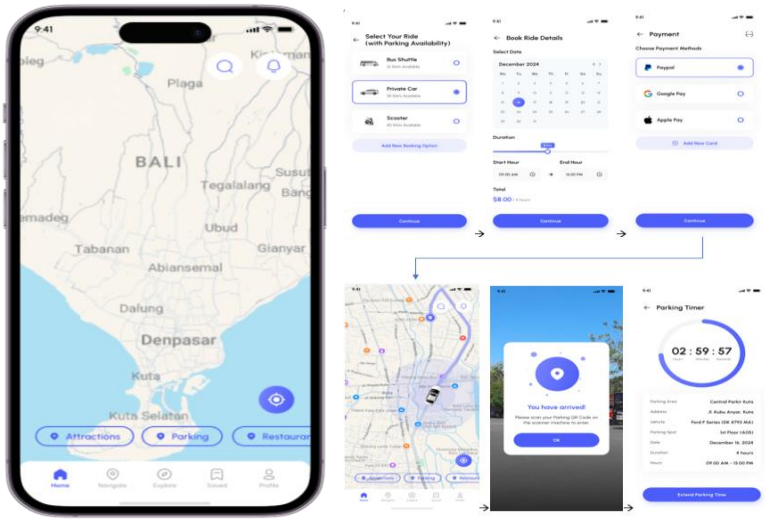

Figure 6. ZoneFlow Parking and Navigation Features

ZonaFlow also provides a feature to search for tourist attractions that include cultural sites and important monuments such as the Bali Bombing Memorial, Bajra Sandhi Monument, Puputan Klungkung Monument, and Taman Ujung Blambangan. Each destination is equipped with information on travel distance, tourism categories, and mobility zones that need to be traversed. After users select a destination (for example, the Monument of Humanitarian Tragedy), the application will display the best route, a combination of transportation modes, estimated time, costs, and walking directions from the parking point to the location.

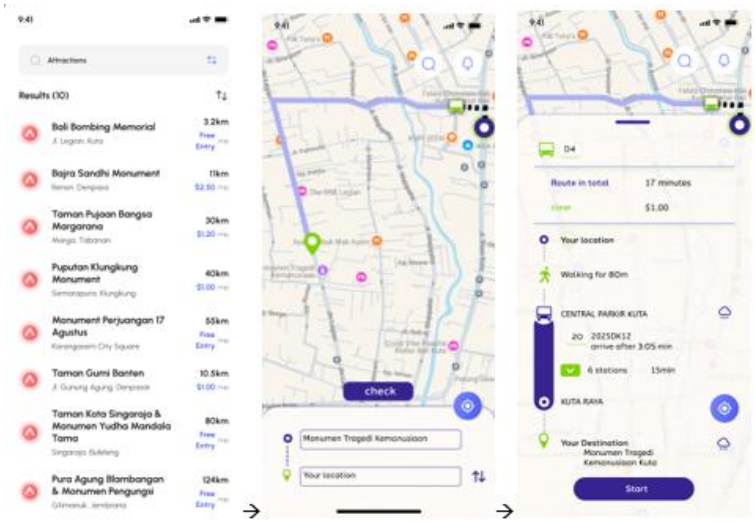

Figure 7. ZoneFlow Tourist Attraction and Navigation Features

The results of the development and simulation of the ZonaFlow design prove that the innovation of a tourism transportation system in Bali can be realized through a digital approach based on the Tourism Mobility Zoning System. This application not only provides navigation services but also functions as an integrated system that combines modes of transportation, zoning information, parking management, and interactive traffic data. This meets the needs of modern tourism that demands comfort, speed, efficiency, and supports sustainability principles.

The application of the Tourism Mobility Zoning System is reflected through features that encourage tourists to park outside dense zones, such as in Central Parking Kuta, and then continue their journey to destinations using transportation that suits the characteristics of the zone. This approach has proven to reduce potential congestion, regulate the flow of tourist movement, and enhance mobility efficiency in dense areas such as Kuta, Sanur, and Ubud. ZoneFlow also provides spatial education to tourists so they can understand the boundaries of the zones set by the local government.

The advantages of ZonaFlow lie not only in technology aspects but also in its contribution to environmental preservation and destination management. Digital features such as the Parking Timer and contactless payment methods encourage vehicle rotation efficiency and minimize congestion. This system also allows managers to monitor tourist movements based on data for more responsive transportation planning to the capacity of the area. Thus, ZonaFlow serves as a bridge between spatial planning policies, transportation zoning, and the direct experience of tourists. Overall, the Tourism Mobility Zoning System proves that the innovative tourism transportation system based on the Tourism Mobility Zoning System is highly relevant, applicable, and can be replicated in other tourist destinations. The integration of technology, regulations, and tourist behavior is a crucial foundation in creating an adaptive, efficient, and sustainable tourism mobility system in the future.

CONCLUSION

This study concludes that mitigating Bali's chronic traffic congestion requires a systemic transition beyond mere physical infrastructure development. The proposed Tourism Mobility Zoning System (TMZS) which categorizes destinations into Transit-Oriented, Car-Free, Pedestrian, and Limited Transport zones conceptually resolves this issue by regulating tourist flows and enhancing mobility efficiency in high-density areas like Kuta, Sanur, and Ubud. Theoretically, this research bridges spatial zoning frameworks with real-time digital technology integration, extending carrying capacity and Transit-Oriented Development (TOD) theories into a novel socio-spatial model tailored for island tourism. Practically, these findings urge policymakers to formally integrate the TMZS framework into regional spatial plans and tourism regulations. Successful implementation demands targeted investments in transit hubs, strict enforcement against illegal parking, and the institutionalization of digital platforms like ZonaFlow to support multi-modal transit integration. While this study provides a robust foundational framework, it is constrained by its geographic focus on three specific areas and its reliance on secondary macro-data. Future research should prioritize empirical studies utilizing primary surveys to capture microscopic tourist mobility behaviors and their acceptance of zoning policies. Furthermore, employing advanced spatial transportation modeling to test TMZS applicability in broader global contexts is highly recommended to validate the system's long-term sustainability.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest. The funding provided by IPB International had no role in the selection of the research project, study design, or the decision to publish the results.

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