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RESEARCH PAPER

Optimizing Pedestrian Safety: A Spatial Analysis Approach to Grade-Separated Pedestrian Crossings in Haripur City, Pakistan

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ABSTRACT

This study aims to explore the application of spatial analysis to identify optimal locations for Grade-Separated Pedestrian Crossings (GSPCs) to improve pedestrian safety. The rise of motorized vehicles has increased dependency on automobiles and reduced pedestrian activities. Despite walking's resurgence due to health benefits, pedestrian safety remains critical, with pedestrians accounting for 50% of road fatalities in Pakistan. Hazardous road-crossing behaviors necessitate effective planning and design of pedestrian infrastructure. This study employs spatial analysis, incorporating global and local radius analyses of vehicular and pedestrian dynamics. This method integrates data on pedestrian safety and vehicular movement, proving objective results compared to the traditional survey methods. Spatial analysis identified optimal locations for GSPCs, providing a framework for enhancing pedestrian safety and optimizing GSPC placement. Meticulous planning is crucial to prevent underutilization and ensure cost-effectiveness. This approach may be extended to other urban areas to enhance pedestrian infrastructure.

KEYWORDS Grade Separation, Pedestrian Crossings, Space Syntax, Spatial Analysis

Introduction

The invention and subsequent proliferation of motorized vehicles have significantly transformed urban environments over time. This shift has led to a marked dependency on automobiles, resulting in a corresponding decline in pedestrian activities (Anciaes and do Nascimento, 2022). Over recent decades, walking has gained popularity as a beneficial activity due to its extensive global, social, and personal advantages, encompassing both physical and mental health. However, the Global Road Safety Facility (World Bank Group) reports that pedestrians constitute 50% of road fatalities in Pakistan (GRSF, 2021). This significant rate of pedestrian casualties is primarily attributed to hazardous road-crossing behaviors, which increase exposure to the risks posed by high-speed vehicular traffic.

The planning and design of walkways aim to separate pedestrians from vehicular traffic, thereby enhancing their safety and reducing the risk of fatal encounters. This separation significantly improves the safety of pedestrian crossings. According to the American Association of State Highway and Transportation Officials (AASHTO) in their Highway Safety Manual, transforming an at-grade, signalized intersection into a grade-separated interchange decreases injury crashes by 28 percent. The implementation of Grade-Separated Pedestrian Crossings (GSPCs) ensures the complete segregation of vehicle and pedestrian traffic, effectively eliminating the barrier effect. However, GSPCs are among the most costly infrastructures to construct, and improper placement can lead to abandonment, vandalism, and economic loss. Therefore, meticulous planning is essential to optimize the operational efficiency of GSPCs.

Literature Review

The presence of roadways imposes both physical and psychological barriers to pedestrian mobility, significantly influencing accessibility. Research indicates that the barrier effect of a road is contingent upon the specific attributes of both the pedestrian crossing infrastructure and the road's characteristics. This effect can manifest as either delays or increased fatality rates. Furthermore, urban traffic congestion has detrimentally impacted the overall quality of life. Recently, public sensitivity to this issue has intensified, rendering traffic-induced delays a critical focus in urban development planning.

In Pakistan, pedestrians represent the most vulnerable group among road users. Key contributing factors to the escalating number of road fatalities and increased vulnerability of pedestrians include insufficient and underutilized pedestrian crossings, as well as the neglect of pedestrians' right of way (GRSF, 2021).

For pedestrian crossings to be effective, they must be strategically planned and optimally located. The lack of pedestrian crossings or their inconvenient placement often compels pedestrians to engage in jaywalking. According to Oxley and collegues (2005), the factors influencing pedestrian crossing behavior encompass the crossing gap, as explained by gap acceptance theory, and the position and frequency of use of the crossing facility, as detailed in utility theory (Oxley et al., 2005). These findings underscore the crucial role of meticulous planning in the design of pedestrian crossings.

The selection of pedestrian crossing types is typically influenced by the characteristics of the roadway (Anciaes and Jones, 2020). For roads with high vehicular speed and traffic density, grade-separated crossings—such as overhead bridges or underground passages—are advised to ensure complete separation and enhanced security for pedestrians. This approach not only guarantees pedestrian safety by removing interactions with vehicular traffic but also reduces potential delays for vehicles (Crawford et al., 2011).

Pedestrian bridges and underpasses are often underutilized due to various factors, including poor approach/accessibility, inadequate design, safety concerns, and environmental comfort (Officials, 2011). Over the past few decades, urban authorities have been increasingly concerned with improving the effective utilization of grade-separated pedestrian crossings.

A study investigating the use of overpass bridges in downtown Ankara through binary logistic regression observed that the choice to use such facilities is habitual rather than random. The study concluded that the usability of these infrastructures could be enhanced by providing escalators for convenience (Räsänen et al, 2007). Another study conducted in Malaysia on the utilization rates of pedestrian bridges identified several factors responsible for the low usage of overpasses, including the direction of flow, traffic volume, distance to the facility, and the presence of fences, all of which significantly impact the use of pedestrian footbridges (Rizati et al., 2013).

For effective utilization of grade-separated pedestrian infrastructures, it is crucial to link land use with pedestrian movement. Identifying the city's spatial structure is necessary to provide efficient pedestrian crossing facilities for potential users (Lee et al.,, 2017). Research in Sri Lanka, which surveyed the criteria for the effectiveness of grade-separated pedestrian crossings, concluded that context-specific designs could significantly improve the utility of these facilities (Bandara & Hewawasam, 2020).

Internationally, the provision of pedestrian facilities follows certain principles. However, even in countries like the USA and the UK, where warrants have been experimented with and developed, there is a need for city-level modifications. These existing guidelines often address macroscopic factors while overlooking microscopic parameters of traffic flow within urban systems (Jain and Rastogi, 2016).

In Khyber Pakhtunkhwa, warrants have been published that focus on the Pedestrian Latent Demand Model (PLDM). This model involves a land-use survey to generate pedestrian infrastructure demand and utilizes the Roadside Pedestrian Conditions Model (RPCM) to measure the level of service (LOS) for existing infrastructures (P&D Department, 2017). By considering accessibility requirements and specific site conditions, such as desired lines, pedestrian and vehicle density, road geometry, capacity, and legal restrictions (e.g., speed limits), grade-separation can become a more convenient and user-friendly facility.

Considering accessibility requirements and specific site conditions i.e., desired lines, number of pedestrians and vehicles (volume/density), road geometry and capacity, and legal restrictions (speed limits) can make the grade-separation facility convenient and user-friendly.

International warrants, on basis of existing knowledge and surveys, proposed that grade-separated crossings would be suitable on college or university campuses, schools, at crossings linking recreation, at main activity centers, close to transit terminals and major stops, and at distinctive sites having very high and concentrated pedestrian flows. (Axler, 1984) That is why adjacent land-use analysis plays an important role in decision-making for the optimal location of the facility.

The case of Haripur City in Khyber Pakhtunkhwa, Pakistan, serves as the basis for this study. Haripur, an old city that used to be the capital of the Hazara region, is rich in natural and man-made resources and is a center for revolutionary industrialization in Khyber Pakhtunkhwa. This has made the city a significant job provider, attracting people to live and work in Haripur and its vicinity, leading to exponential urban growth and traffic congestion. Consequently, careful and targeted planning of transport infrastructure is necessary.

Haripur is located north of the famous Karakoram Highway (KKH), similar to many cities along the KKH. Recently, the city has expanded south of the highway due to urban growth, making the highway a barrier for pedestrian movement within the neighbourhood.

Material and Methods

To investigate pedestrian behavior within the context of walking comfort and to analyze vehicular densities in terms of choice and integration, a comprehensive spatio-syntactical analysis of the city's fabric was conducted. The methodological approach involved several key steps:

- Base Map Generation: The city’s base map was created using AutoCAD software, integrating data from Google Earth and field surveys. This provided an accurate and detailed spatial representation of the urban environment.
- Segment Analysis: Depthmap software, developed in the Space Syntax Laboratory at University College London (UCL), was employed for segment analysis of the city’s spatial structure. This analysis utilized both global and local radii to differentiate between vehicular and pedestrian dynamics.
- Global Radius: Used to identify vehicular flux, providing insights into areas of high vehicular traffic and their integration within the broader urban network.
- Local Radius: Applied to determine routes of pedestrian interest, highlighting pathways that offer comfort and accessibility for pedestrians.

- Cross-Validation: The gate count method was utilized to validate the results generated by the software. This involved empirical counts of pedestrian and vehicular movements at various city gates to ensure the accuracy of the computational analysis.
- Data Visualization: The results were visualized using scatterplots, facilitating a clear comparison between the observed data and the predicted patterns of pedestrian and vehicular movement.

This multi-faceted approach allowed for a detailed understanding of the spatial dynamics influencing both pedestrian comfort and vehicular integration within the urban fabric.

Karakoram Highway passing through the city was the subject of interest for the provision of grade-separated pedestrian crossings (GSPCs) highlighted in red. The figure shows the existing GSPC facility in yellow and the secondary routes for study in black.

Segment Analysis

This study utilized Depthmap software for spatial analysis, focusing on key decisions integral to the research. The analysis was based on both global and local radii, which provide insights into the city center and locally active neighborhoods, respectively. Specifically, the global radius corresponds to vehicular movement patterns, while the local radius pertains to pedestrian areas of interest.

For this study, the global radius (n) was defined by the dimensions of the input base map, and the local radius was set at 10% of the global radius. Depthmap's analysis yielded numerical values represented by a color gradient, with red indicating higher values and blue indicating lower values. The analyses were conducted for both integration and choice metrics.

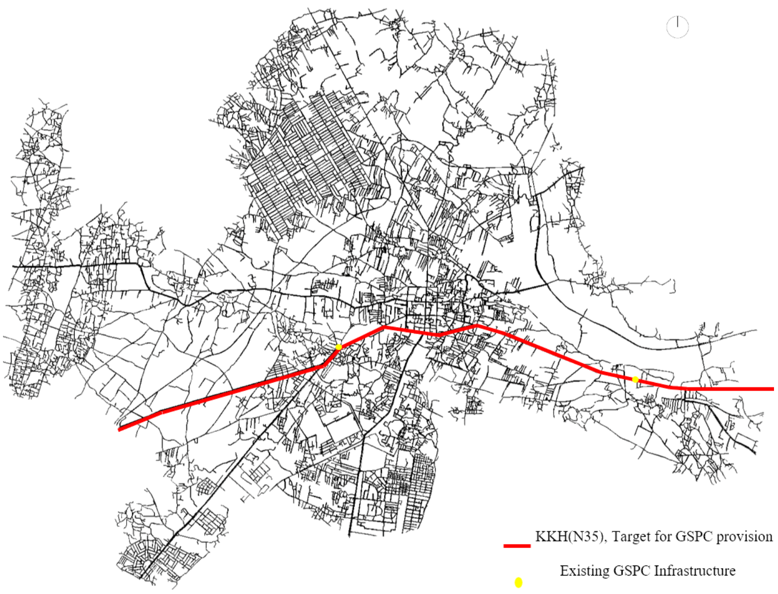

Figure 1: Base Map of Haripur City

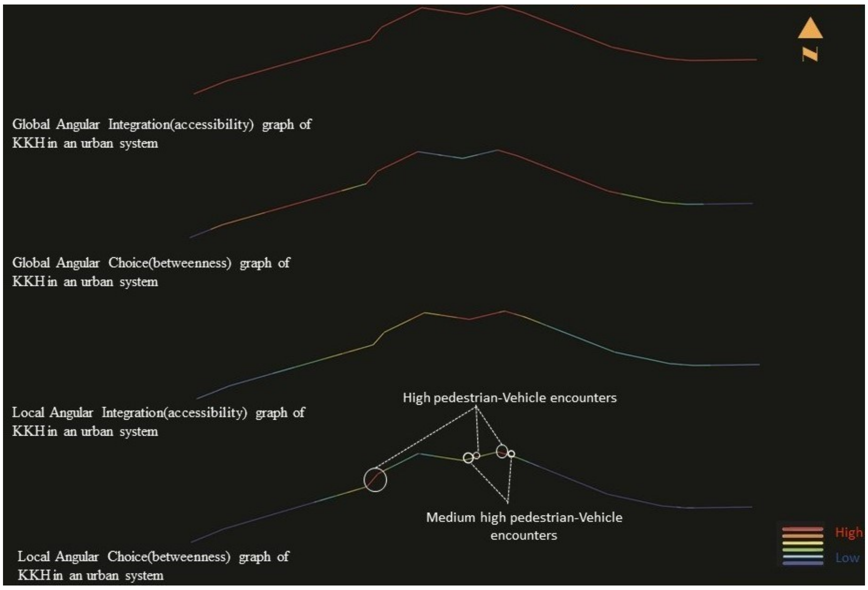

Figure 2: Overlapping the high flux of vehicles and pedestrians

The two measures under consideration reflect the fundamental elements of human movement: integration and choice. Integration pertains to the ease of accessing a destination, whereas choice pertains to the selection of a route, reflecting the flow of movement. Integration is calculated, while choice is a cognitive measure. Conflict point data is correlated with field observations using the gate-count method developed by the Space Syntax Laboratory at University College London (UCL). This method involves randomly selecting gates at various points within the study area. Observers mark an imaginary line on the street, referred to as a gate, and count the number of vehicles and pedestrians passing through it. For this study, 15 gates were marked on the Karakoram Highway (KKH) and observations were conducted during peak morning and afternoon hours.

Figure 3(a): Gates on KKH (G1-R to G15-L)

Figure 3(b): Imaginary line for Gate at G3

The choice analysis graph provides valuable insights into the hierarchy of urban routes, offering crucial information about the most vital and active routes within a given region. However, in large systems, the sheer magnitude of the values can be overwhelming, complicating comparative studies. To address this, the concept of Normalized Angular Choice (NACH) is employed. NACH is calculated using the formula:

NACH = Log (Choice (r)+1)/Log (Total depth (r)+3)

This normalization facilitates the comparison of streets within the system and enables a more coherent analysis of the correlation between the calculated values and observed field data.

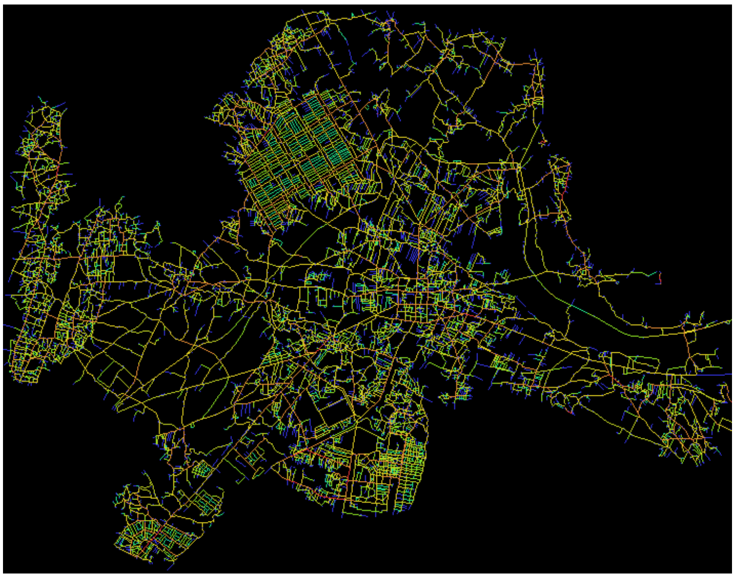

Figure 4: Normalized Angular Choice Source

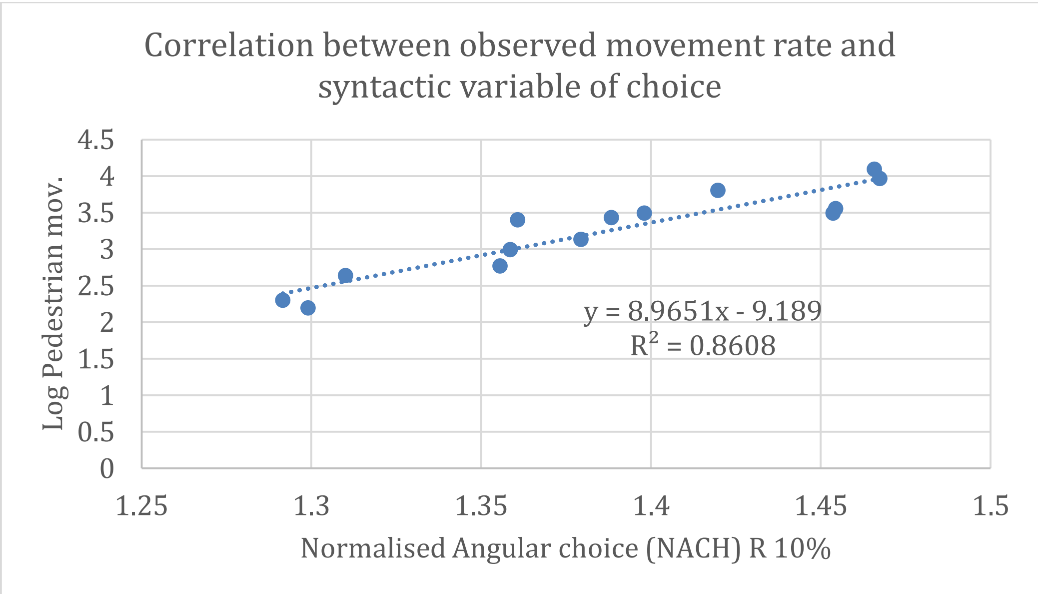

Figure 5: Correlation of NACH and log of pedestrian count

The correlation observed in this study substantiates the validity of depth map analysis data for decision-making purposes. This is evidenced by the scatterplots, which depict a correlation between the observed data and the software-generated data. The correlation coefficient of 0.8, which approaches 1, signifies a strong correlation.

Consequently, the application of space syntax theory via depth map analysis emerges as a robust methodology for informing sustainable urban transport planning decisions.

Conclusion

The spatial configuration of urban settlements plays a pivotal role in establishing a foundation for sustainable urban transport infrastructure. This study employed spatial analysis through Depthmap to suggest optimal locations for the General Service Pedestrian Crossings (GSPCs) in Haripur city. This method proved to be more efficient and time-saving compared to conventional surveys. The analysis focused on both integration and choice for vehicle and pedestrian movement, with the overlapping values indicating the highest average being used as the primary criterion for positioning GSPCs.

This research model demonstrates the potential for effectively positioning GSPCs in Haripur to enhance the transport system's efficiency. The methodology can be extended to other urban areas, particularly those near highways, to plan GSPC infrastructure or other crossing facilities. By improving accessibility, connectivity, and continuity for pedestrian movement, this approach can significantly contribute to the development of sustainable urban transport systems.

Recommendations

Implementation in Haripur: The findings of this study may be utilized to strategically position GSPCs in Haripur, ensuring the placement and locations that maximize pedestrian and vehicular integration and choice.

Expansion to Other Urban Areas: the application of this spatial analysis model may be extended to other urban developments, particularly those adjacent to highways, to plan and optimize pedestrian crossing facilities.

Policy Development: this study may help develop policies that incorporate spatial analysis tools like Depthmap in urban planning processes, particularly for transport infrastructure projects.

Further Research: further research to refine the spatial analysis techniques and explore their application in different urban contexts, may ensure a broader applicability of the model.

By adopting these recommendations, urban planners and policymakers can create more sustainable, efficient, and pedestrian-friendly urban transport systems.

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