P-ISSN: 2709-6254	Journal of Development and Social Sciences	Apr-June 2024, Vol. 5, No.2
O-ISSN:2709-6262	https://doi.org/10.47205/jdss.2024(5-II)54	[577-585]

Journal of Development and Social Sciences
www.jdss.org.pk

RESEARCH PAPER

A Planning Study on the Spatial Configuration of Buss Rapid Transit Stations-Focused on Sustainable Mobility

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ABSTRACT

Mass transit systems are pivotal for fostering sustainable transportation and tackling urban mobility challenges. However, their efficacy hinges significantly on spatial characteristics, accessibility, and integration with the built environment. This study offers a blueprint for future Bus rapid transit station designs, aiming to boost ridership and broaden catchment areas to optimize mass transit planning within their surrounding context. Achieving this entails an exploration of human travel behaviors and their interplay with the built environment. To address these challenges, space syntax was utilized as a spatial analysis tool for mass transit system of Rawalpindi, Pakistan, considering its surrounding context. The study's outcomes are based on spatial comparative analysis and gate count analysis, assessing how accessibility impacts user flow to specific stations. The findings underscore the negative linear correlation between ridership and integration, with stations demonstrating higher integration experiencing lower ridership and vice versa. This underscores the significance of spatial analysis in optimizing mass transit networks, mitigating environmental impacts, and enhancing urban livability. Planners and policymakers can leverage these insights to tailor station designs, improving accessibility and flow. Additionally, integrating other transit modes can expand catchment areas, aligning with research emphasizing integration's importance.

KEYWORDS Accessibility, Strategic Location of Metro Stations, Sustainable Transport; Walkability, Space Syntax

Introduction

Transportation plays a crucial role in shaping cities and sustainability. The increasing concerns over environmental degradation, traffic congestion, and energy consumption, there is a growing need for sustainable transportation options. Mass transit systems have gained recognition as sustainable transportation option due to its ability to carry large numbers of passengers, reduce traffic congestion, and lower overall carbon footprint (Wright, 2002). To fully leverage the benefits of mass transit, it is essential to conduct a comprehensive spatial analysis of the relevant systems and understand their role in fostering sustainable urban development. Bus Rapid Transit (BRT) systems are often implemented alongside Travel Demand Management (TDM) strategies, to create appropriate incentives for sustainable transportation choices. This integration of BRT and TDM contributes to a cohesive and efficient urban mobility landscape (Wright, 2002). For any feasible means of transportation to be successful, accessibility to the Stations is a crucial factor. This have a significant impact on how the BRT system is used, especially in areas with a high traveler potential, dense housing, a high concentration of workplaces, and attractions in addition to shopping, sporting, and entertainment districts. Areas close to the station are where the majority of passengers in public transport systems originate. To benefit all users, streets near transit terminals must accommodate buses, bicycles, and pedestrians, as they represent diverse modes of transportation (Landex et al., 2006). Recent research demonstrates how network centralization has increased in importance, in spatial network analysis, such as the integration of metro network topological connection (Cao et al., 2020). Lahoorpoor & Levinson (2020), highlighted how station entry and exit sites may impact accessibility for passengers of the to-metro, and how exposing the current system may boost ridership. (Lahoorpoor & Levinson, 2020).

In earlier research the importance of public transportation use to the urban transportation network has been covered. A large number of these link user travel habits with the riding rate. Travel mode selection, travel behavior, trip time, and travel expense are a few common factors that have been taken from earlier studies. The ridership count of stations can also be determined by a few other factors that have been outlined as being crucial. The axis representation of spatial syntax is used in the research conducted by Wu & Zhou (2023) to quantify the practicality of the to-metro using the topological characteristic of the street in the station's catchment (Wu & Zhou, 2023).

Spatial analysis plays a crucial role in understanding the spatial characteristics and patterns of mass transit systems and their relationship with the built environment. It is a method for representing, quantifying and interpreting spatial arrangement in buildings and settlements. (Hillier et al., 1987; Ullah & Park, 2016). The concept of space syntax encompasses theories and methods to analyze spatial arrangements, breaking down spaces into components (Gomaa et al., 2024; Ullah et al., 2023; Ullah et al., 2022). This approach involves transforming them into networks of choices, and subsequently representing them as maps and graphs that depict the interconnectedness and integration of these spaces. It involves the examination of various spatial factors, such as the distribution of transit stops, connectivity of routes, accessibility measures, and the impact of land use patterns on transit demand. It provides insights into how the physical layout of urban environments influences people's movement patterns and interactions (Din et al., 2023). It also aids in identifying potential barriers to transit usage, such as physical barriers, inadequate infrastructure, or poorly designed routes, allowing for targeted interventions to improve transit service (Wright, 2002). Integration, a fundamental idea in space syntax, refers to the connection of a certain origin to all other spaces. It provides insights on relative depth and space relationships that are crucial for urban planning and design decisions that aim to maximize accessibility and the overall functionality of built environments (Stegen, 1997). Where Choice is a method for measuring the movement of a street segment or an axial line over a predetermined distance in a predetermined space or throughout the entire system of all parts (Hillier et al., 1986). Space Syntax analysis can be applied to BRT planning studies to understand the potential impacts of spatial configuration on passenger flows, accessibility, and overall system efficiency. It could help identify critical locations for BRT stations, optimal route alignments, and potential improvements to the urban fabric to enhance sustainable mobility (Stegen, 1997).

The main objective of this research is to analyze the spatial characteristics of bus rapid transit stations of Rawalpindi commonly known as Rawalpindi Metro, such as the distribution of transit stops, route connectivity, and accessibility measures and assessing the relationship between land use patterns and mass transit demand to understand the impact of built environment on transit usage.

Literature Review

Sustainable transport plays a pivotal role in fostering economic growth, enhancing the efficient movement of goods and people, and promoting social equity by offering accessible options across all demographics (Kowalczyk, 2014). Moreover, it contributes to environmental preservation by mitigating pollution and congestion, thereby aligning with the three pillars of sustainable development: economic prosperity, social inclusivity, and environmental stewardship. Given the escalating demand for transportation and its associated impacts, there is a pressing need to bolster the sustainability of the transport sector to meet the objectives of sustainable development and climate action (Litman, 2009).

This imperative is underscored by the inclusion of environmentally friendly transportation as a core subject in the 2030 Strategy for Sustainable Development, which facilitates the attainment of at least 8 out of the 17 Sustainable Development Goals (SDGs) (Livingstone & Rogers, 2003).

The discourse on sustainable urban development increasingly emphasizes the pivotal role of public transportation in fostering livable cities with enhanced accessibility (Richardson, 2005). However, while accessible public transportation systems like trains, trolleys, buses, and trams contribute to urban vibrancy, they alone do not encapsulate the essence of modern, sustainable cities. Mass transit systems emerge as sustainable transportation alternatives, capable of accommodating large passenger volumes, alleviating traffic congestion, and reducing carbon emissions (Belzer & Autler, 2002). Through their efficiency, cost-effectiveness, and environmental friendliness, these systems promote improved air quality, reduced energy consumption, and heightened mobility (Lovasi et al., 2012).

BRT systems, often complemented by Travel Demand Management (TDM) strategies, exemplify integrated approaches to sustainable urban mobility (Wright, 2002). By incentivizing sustainable transportation choices, such systems contribute to a cohesive and efficient urban transport landscape. Notably, accessibility to metro terminals emerges as a crucial factor in promoting mobility solutions and fostering inclusive and sustainable transport networks (Landex et al., 2006).

Spatial analysis, particularly within the framework of Space Syntax, offers valuable insights into the spatial characteristics and patterns of mass transit systems, informing strategic planning and design interventions (Hillier et al., 1986). By elucidating the relationship between spatial configuration and human behavior, Space Syntax aids in optimizing transit networks, enhancing service coverage, and identifying barriers to transit usage. It also facilitates the development of Transit-Oriented Development (TOD) strategies that promote compact, mixed-use developments around transit nodes, fostering sustainable urban growth (Dursun, 2007).

Sustainable transport is indispensable for achieving the goals of economic development, social equity, and environmental sustainability. Through integrated approaches encompassing public transportation, BRT systems, and spatial analysis techniques like Space Syntax, cities can forge inclusive and resilient transport networks that cater to the diverse needs of their inhabitants while minimizing environmental impacts.

Material and Methods

This study was carried out on the bus rapid Transit system of Rawalpindi region, of Pakistan commonly known as Rawalpindi Metro Bus Service. The study area covered 8.6km area and 10 stations from Saddar Terminal to Faizabad Terminal. The circular catchment area technique was employed in this study, which is focused on looking at catchment areas inside a circle 600 meters from the stations.

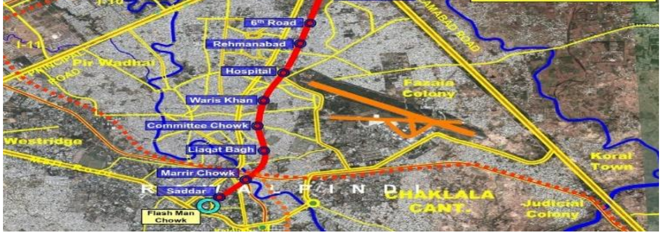

Figure 1 Study Area: 10 Metro station of Rawalpindi

To initiate the spatial analysis, the study commenced by gathering spatial information like maps and the primary street layout utilizing Google Maps. Following data acquisition, axial lines—a representation of street networks—were created as the first step in spatial syntax research. Open Street Maps were used to produce the Street network. As a result, the axial lines in this work were manually produced in AUTOCAD. The next stages of space syntax analysis used an axial map. Studying the connections between pedestrian flow to each station and street morphology, based on the axial maps for each station. The least number of the lengthiest straight lines that can be drawn in open areas can be found on the axial map (Hillier et al., 1993).

A "Gate Counts" is a technique pioneered by the UCL Space Syntax Laboratory is utilized to monitor the flow and patterns of pedestrian and vehicular movement within urban layouts and buildings. It is an imaginary line that the observer draws across a street or space. To quantify the volume of movement, the observer records the number of pedestrians or vehicles crossing this designated gate (Yamu et al., 2021). To ensure comprehensive observations, a series of gates encompassing the entire study area were chosen. These observations were carried out on weekdays during peak hours, specifically from 1:00 pm to 5:00 pm. One gate was picked across each station in the Rawalpindi city, for measuring ridership.

The heat scale indicates cold (blue color) which is segregated area to hot (Red color) which is highly integrated area (Hillier & Hanson, 1989). Space syntax, Integration is a normalized measure of distance from any a space of origin to all others in a system. In general, it calculates how close the origin space is to all other spaces, and can be seen as the measure of relative asymmetry (or relative depth). Normalized choice aims to solve the paradox that segregated designs add more total (and average) choice to the system than integrated ones.

NACH = log (Choice+1)/log (TotalDepth+3)

Result and discussion

The visualization depicted in Figure 2 showcases integration levels (HH) across different areas, employing a spectrum of color gradients from cool tones representing segregated regions to warm hues denoting highly integrated locales. As the color spectrum transitions towards shades of orange and bright red, the degree of integration surpasses, illuminating effectively integrated zones within the neighborhood. This graphical representation offers a succinct overview of segregation and integration levels across various regions.

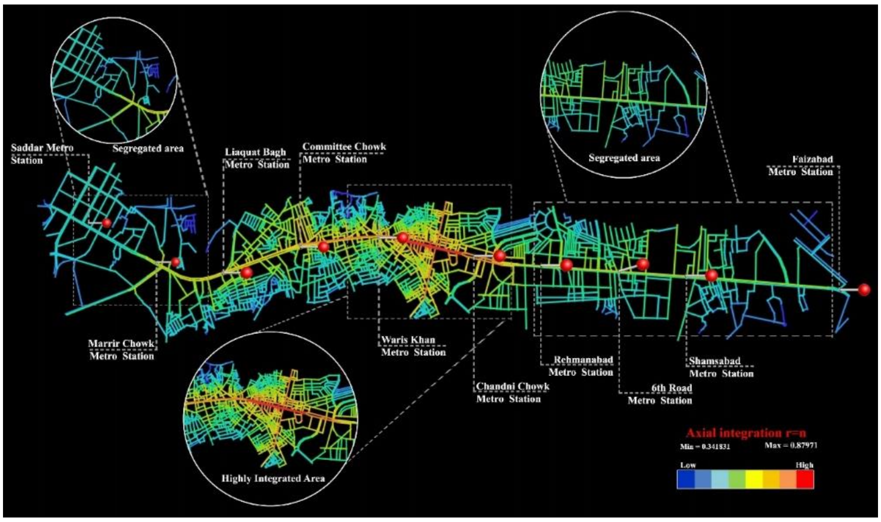

Figure 2 Integration map

Further analysis focused on a route line, meticulously segmented to discern integration values along its entirety. This segmentation strategy facilitates a detailed examination, with each point along the route assigned an integration value based on segment integration metrics. By adopting this approach, a comprehensive understanding of integration dynamics along the route was attained, elucidating connectivity and cohesion levels within each segment. Thus, visually representing integration values along the route line offers nuanced insights into the social and spatial dynamics shaping the traversed area.

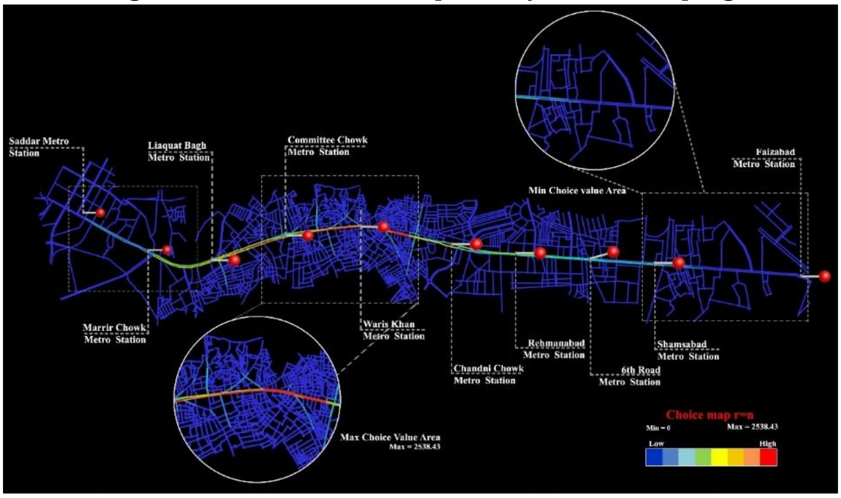

Figure 3 Choice values

In the context of space syntax analysis, choice value assessment, evaluates different routes within a spatial context, considering factors such as connectivity and accessibility. In densely populated areas like Waris Khan Station and Committee Chowk, characterized by high pedestrian footfall, elevated choice values signify preferred paths. Intriguingly, a reciprocal relationship between choice values and ridership counts emerges, wherein increased choice values correlate with decreased ridership as shown in figure 3. This observation underscores the complexity of commuter behavior, influenced by factors beyond mere path preference, such as distance and alternative transportation modes.

Normalized angular choice (NACH) values were employed in this study for their clarity and consistency over raw values. Utilizing the equation NA Choice _n= log (A Ch_n+1)/ log (A TD_n+3)), a robust integration value (R= 1.6231) is determined, highlighting the highest integrated area. Notably, a significant r-value was observed between Liaqat Bagh and Committee Chowk, indicating a substantial level of integrated space. Specifically, the highest r-value of 1.62 is identified in this area, cementing its status as the most integrated space among the studied stations.

Figure 4 NAch analysis.

Table 1
Table of Station with ridership-integration-choice values

Name of the Station	Average Ridership	Integration (HH)	Angular choice
Saddar	8,906	0.556	1.391806
Marrir Chowk	3,520	0.673	1.448961
Liaquat Bagh	2,452	0.767	1.569789
Committee Chowk	3,639	0.79	1.471748
Waris Khan	1,689	0.803	1.591013
Chandni Chowk	2,359	0.797	1.530566
Rehmanabad	3,544	0.696	1.573157
6th Road	3,539	0.696	1.49218
Shamsabad	2,940	0.696	1.450708
Faizabad	7,677	0.562	1.271949

Regression analysis was employed to elucidate the relationship between ridership and integration, yielding a statistically significant association with a p-value of 0.00031 and R^2 value of 0.8196. This indicates that approximately 82% of the variability in ridership can be explained by changes in integration values, underscoring a strong negative correlation between the two factors. The derived regression equation (y = -23.757x + 20.695) allows for the estimation of average ridership for integration values greater than 0. Given this negative correlation, strategic interventions aimed at enhancing ridership are recommended to consider the potential impact of spatial integration.

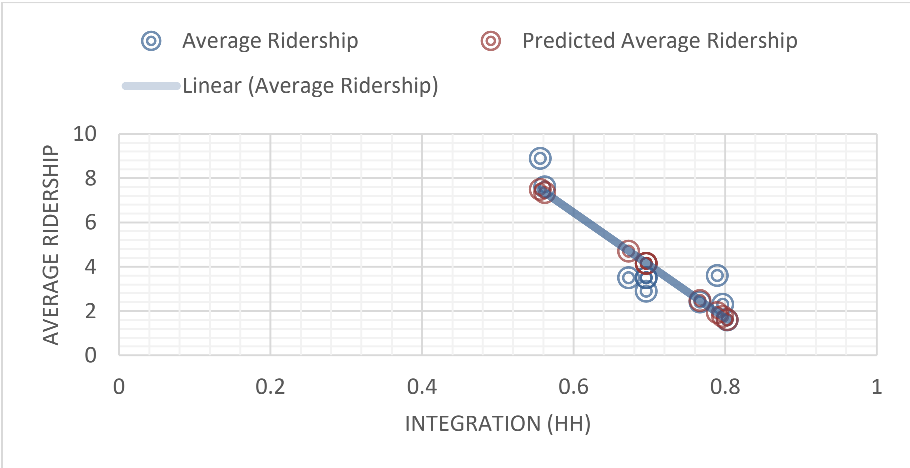

Figure 5 Regression Analysis of Average Ridership and Integration (HH)

Conclusion

Space Syntax provided a comprehensive view of the route network of the built environment, therefore allowing an easy way to map how specific interventions would impact the whole network. Results suggests a strategic effort to optimize resources and enhance the overall efficiency of the station's accessibility in response to lower ridership numbers by integrating other transport modes. Given the strong negative correlation between ridership and integration, prioritizing initiatives to enhance integration could bolster ridership numbers. Exploring innovative strategies to streamline transportation connections and improve accessibility might prove beneficial. Additionally, conducting further research to understand specific factors driving this correlation could inform targeted interventions aimed at optimizing ridership outcomes.

Based on the strong correlation observed between integration and ridership, it's evident that investing in integration is a promising strategy for enhancing urban transit systems. By measuring the index of urban activity, we can pinpoint routes with the highest urban activity, making them prime candidates for transit integration. Focusing on these routes allows for more efficient allocation of resources and targeted improvements. By strategically integrating various modes of transportation like walking and cycling tracks along routes with high urban activity, can enhance accessibility, efficiency, and sustainability within transit systems. While station relocation may pose challenges, prioritizing integration efforts presents a cost-effective strategy to maximize ridership and expand catchment areas. By carefully improving connectivity between stations and alternative transportation modes, a more seamless and attractive transit experience can be fostered, while advancing broader urban development goals.

The application of Space Syntax in Bus rapid transit station design is an advanced approach for enhancing spatial layout and operation, hence increasing ridership in urban transportation networks. Planners might use spatial analysis tools to predict ridership during the planning process, allowing for precise station position size determination and strategic allocation of space for mobility, parking, and seats. Transit authorities may design stations with adequate capacity and passenger comfort by adjusting station designs based on expected demand, resulting in maximum efficiency and accessibility while supporting sustainable urban mobility. Overall, the implementation of this study provides a strategic framework for enhancing integration, ridership, and overall performance.

Recommendations

Based on the conclusions drawn from the analysis, the following recommendations are listed for enhancing urban transit systems:

1. Based on the strong negative correlation between ridership and integration, it's crucial to consider spatial matrix of the transit network. Initiatives aimed at improving the connectivity between various transportation modes can significantly bolster ridership numbers.
2. The use the Space Syntax analysis to identify routes with the highest urban activity for transit integration and improvements, resources can be allocated more efficiently, leading to better overall performance of the transit system.
3. Integration of various modes of transportation, such as walking paths and cycling tracks, along routes with high urban activity, could improve accessibility, efficiency, and sustainability, making the transit system more attractive and user-friendly.
4. Specific factors driving the correlation between ridership and integration could inform targeted interventions, optimizing ridership outcomes and improving the strategic planning of transit networks.
5. Improving the connectivity between stations and alternative transportation modes, may create a more seamless and attractive transit experience, expanding catchment areas and advancing broader urban development goals. Prioritizing integration efforts presents a cost-effective strategy to achieve these objectives.

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