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Rail transit and urban spatial decentralization: a case study of Boston’s multi-centered urban evolution

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Abstract. In the context of modern urbanization, excessive concentration of population and economic activities in core areas has intensified problems such as congestion, housing shortages, and environmental stress, prompting cities to evolve toward multi-centered spatial structures. This study explores the interaction between rail transit accessibility and urban spatial decentralization, using Boston as a representative case. Drawing on accessibility theory, decentralization theory, and the Transit-Oriented Development (TOD) model, the research combines theoretical analysis with empirical observation to examine how Boston’s century-long rail transit evolution has guided the redistribution of population, industry, and land use. The findings reveal that improved accessibility along rail corridors has fostered the emergence of new sub-centers—such as Kendall Square, Alewife, and Quincy Center—where innovation, residence, and commerce coexist, forming a balanced polycentric structure. The study concludes that rail transit acts not only as a transportation system but also as a structural mechanism for spatial reorganization, enhancing economic vitality, social equity, and environmental sustainability. Limitations include reliance on secondary data and contextual constraints of the Boston case. Future research should integrate GIS-based spatial modeling and comparative analyses across diverse urban contexts to further clarify the causal mechanisms linking transit development and spatial restructuring.

Keywords: rail transit, urban decentralization, accessibility theory, TOD model, Boston case study

1. Introduction

In the process of modern urbanization, factors of production, such as population, capital, and industry, are increasingly concentrated in core areas with advantageous locations, driven by the agglomeration effect of scale, forming high-density urban centers. However, problems such as environmental degradation, traffic congestion, housing shortages, and job competition brought about by excessive agglomeration have gradually weakened the attractiveness of central areas, prompting the evolution of urban spatial structure from a single center to a multi-center structure. In this process, rail transit, as the backbone of urban space and the lifeblood of economic operations, has profoundly influenced the layout of urban functions and spatial organization. The layout of rail transit not only determines accessibility patterns for residents and business location, but also reshapes the city's socioeconomic networks and spatial hierarchy over the long term. Boston, a major economic and cultural center in the northeastern United States, exemplifies the development of its rail transit system. Since the opening of the nation's first subway line in 1897, the Boston subway system has evolved over a century, expanding from a single central structure to a multi-node radial network, profoundly promoting the diffusion of urban functions from the core to the periphery [1]. This study will systematically analyzes the interactive relationship between rail transit accessibility and urban spatial decentralization, using Boston as a case study, to uncover the mechanisms by which rail transit promotes urban spatial rebalancing and coordinated regional development. Combining theoretical and case studies, this study assesses the temporal evolution of rail transit accessibility and its impact on population density, land use, and the distribution of economic activity. Drawing on Boston's experience and case studies, this study will deepen theoretical understanding of the relationship between rail transit and urban spatial evolution and provide practical insights for sustainable transit-oriented development (TOD) in rapidly urbanizing regions.

2. Theoretical framework

2.1. Accessibility theory

The term "accessibility" was first proposed by transportation geographer Hansen in the 1950s to measure the convenience of one area reaching another [2]. It encompasses not only spatial distance but also reflects time cost, travel efficiency and the total amount of opportunities for socio-economic activities. In urban transportation research, accessibility is often used to assess the relationship between transportation systems and land use: the more convenient the transportation, the more active the flow of people and resources, and the higher the regional development potential [2]. The construction of rail transit usually significantly enhances the accessibility of the areas along the line. The high-density, punctual and round-the-clock operation of subways and light rails has enhanced the accessibility between different functional areas within the city, thereby leading to an increase in land value and a reorganization of functional layout. The improvement of accessibility means that people's living and working circles can be extended on a larger scale, and it also promotes the spatial redistribution of commercial and residential activities. Take Boston as an example. Its subway system connects the academic district, commercial district and residential district, constantly breaking through the spatial boundaries of urban activities. Accessibility has become an important driving force for shaping the urban structure.

2.2. Decentralization theory

Urban decentralization is a key trend in urban spatial evolution. Classical urban economics theory (such as Alonso's land rent model) suggests that land rents, traffic congestion, and environmental pressures in central areas can drive some residents and businesses to the periphery, forming new secondary centers. Decentralization is not simply a process of "diffusion," but rather a process of restructuring from a central to a multi-core structure [3]. In the late 20th century, with the development of motor vehicles and rail transit systems, urban space gradually evolved from a "single-core, radial" structure to a "multi-center, networked" one [4]. Rail transit construction played a crucial role in providing spatial support and structural guidance in this process. On the one hand, it reduced commuting costs between peripheral and central areas, stimulating the development potential of peripheral areas. On the other hand, it promoted the distribution of economic and social activities along rail lines, forming a series of "sub-centers" with complementary functions.

In this process of decentralization, rail transit is not only a form of transportation infrastructure but also a spatial organizational mechanism. Through networked connections, it redistributes urban resources, enabling a more balanced flow of population, capital, and industrial activities across a wider area, and promoting the transformation of cities from a "centralized" to a "decentralized" and even "multi-core, complex" structure.

2.3. The TOD model theory

The TOD (Transit-Oriented Development) model, which is a development model oriented towards public transportation, originated from the urban planning concept in the 1990s. It emphasizes the high-density and mixed-function development around rail transit stations, enabling residents to complete activities such as work, residence, shopping and leisure within walking or short-distance travel, thereby reducing their reliance on private cars [5]. The core idea of TOD is "driving development through transportation". Rail transit stations are not only transportation nodes but also gathering points for economic and social activities. Compact development around the site can enhance land use efficiency, invigorate the economy along the line, and shape pedestrian-friendly urban Spaces. A typical TOD community usually has a clear public space structure: the station is at the core, with residential, office and commercial facilities laid out around it, forming a mutually reinforcing relationship between public transportation and urban life.

In Boston, the development of Kendall Square and Alewife districts embodies the practice of the TOD concept. The extension of rail transit not only brings greater accessibility but also enables the formation of industrial clusters and residential circles centered on subway stations in the surrounding areas, promoting the transformation of cities from traditional central districts to a diversified spatial pattern.

3. The Boston case: rail transit and urban spatial transformation

3.1. Overview of Boston's rail transit development

At the end of the 19th century, Boston, as one of the earliest cities in the United States to achieve industrialization, was confronted with the problems of rapid population growth and severe road traffic congestion. To relieve the pressure on ground traffic, in 1897, Boston opened the first underground rail line in the United States - the subway section from Boylston Station to

Park Street Station [1]. This line later became part of today's Green Line. This move marks the beginning of the era of urban rail transit in the United States. In 1965, the Boston Transportation Authority officially named each route by color, making the system more intuitive and standardized. At present, the Boston Subway has five main lines, approximately 90 stations, and a total mileage of over 50 kilometers, forming a high-density rail transit network that runs through the urban and suburban areas. The continuous improvement of rail lines not only alleviates urban congestion but also provides channels for the spatial diffusion of population, industries and educational resources.

The Boston subway system is structured around four main lines: green, orange, blue and red. Among them, the green line is further divided into four branch lines (B, C, D and E), which together form the densest rail structure in the city's core area [6]. The four main lines are arranged in a typical radial pattern - extending from the city center in all directions, but interweaving into a network in the core area, forming a transfer system similar to a "#" shape. This structure has significantly enhanced the flexibility of travel and made the commuting connections between different urban districts closer. From the perspective of spatial characteristics, the layout of the track system shows a distinct "center-periphery" structure. The city center area is densely populated with stations and offers convenient transfer. The peripheral areas extend in a band-like pattern along the line, forming a "corridor-style" development pattern. The coverage of rail transit enables most urban areas to reach the city center within 30 minutes, achieving efficient temporal and spatial accessibility. This layout not only facilitates residents' commuting but also promotes interaction among the education district, research district and commercial district, laying the foundation for Boston to form a multi-centered urban structure.

3.2. Analysis of the decentralization trend of Boston rail transit

3.2.1. Functional reconstruction of the central urban area

The efficient connectivity of the rail transit system has made the downtown area of Boston a highly concentrated region of high-end service industries that rely on "face-to-face communication", such as finance, consulting, and creative industries. According to the Global Financial Centres Index (GFCI) report, Boston has long ranked among the top global financial centers, demonstrating its strength and attractiveness in the financial services industry [7]. Against this backdrop, rail transit lines (such as the Red Line and the Orange Line) have enhanced the temporal and spatial accessibility between the city center and the surrounding areas, bringing about improvements in commuting efficiency for financial practitioners. Meanwhile, some industries with large space demands and relatively low added value (such as data processing, large customer service centers, warehousing services, etc.) are gradually spreading along the rail lines to the peripheral areas due to the combined effects of land costs, space rotation demands and transportation accessibility. This diffusion, on the one hand, has released development space for high-end services in the city center, and on the other hand, has also promoted the industrial structure transformation and functional renewal of the areas along the rail transit. Some large financial or investment institutions are showing a trend of moving their customer service or back-office service centers out of the city center and along the rail transit lines to free up office space in the city center.

3.2.2. Spatial reconstruction of separation of work and residence

With the extension and densification of rail transit lines, cities along the Massachusetts Bay Transportation Authority (MBTA) have shown a trend of residential space spreading to the suburbs or along the rail lines. This trend has to some extent alleviated the housing pressure in the city center, while also promoting the intensification of the "separation of work and residence" situation. Take Somerville (adjacent to downtown Boston and along the extension of the Green Line of the subway) as an example. The city has set a goal of adding 6,000 new residential units, creating 30,000 jobs, and developing 125 acres (about 50.6 hectares) of public accessible space by 2030 [8]. For instance, the central area of Malden (near Malden Center Station) has been designated as a key TOD (Transaction-Oriented Development) area. The local government has positioned it on its official website as a demonstration zone for "developing high-density mixed-use residential, commercial and retail communities by taking advantage of rail transit and the walking accessibility of the surrounding area." Therefore, it can be seen that rail transit not only changes the layout of urban living and working Spaces, but also forms a new pattern in the areas along the lines where residential development and commuting convenience work together.

3.2.3. Aggregation and integration of key nodes

One of the notable features of Boston's decentralization is that the transfer hubs and terminal stations of its rail transit are gradually evolving into the new core of the city's functions. These nodes play the role of spatial organization hubs in the urban structure. They are not only important nodes for traffic flow but also concentrated areas for economic and social activities. The high accessibility of rail transit makes the flow of people, information and capital smoother, thereby promoting the redistribution of urban functions and the reallocation of resources.

Take the red line as an example. The Cambridge area where Harvard University and the Massachusetts Institute of Technology are located is a typical representative of Boston's innovation ecosystem [9]. Relying on the transportation advantage of the subway station, the Kendall Square area has attracted a large number of biotechnology and high-tech enterprises to settle in, and has formed close interaction with the scientific research system of universities. This combination of "transportation convenience and knowledge spillover effect" embodies the core logic of accessibility theory: rail transit not only enhances travel efficiency but also promotes the spatial agglomeration of high-end industries in an intangible way.

This process simultaneously confirms the synergy between decentralization and the TOD model [5]. With the continuous extension of the rail network, urban activities have spread from a single center to multiple nodes, and the TOD planning concept ensures that a composite and pedestrian-friendly spatial structure is formed within these nodes. For example, in Kendall Square, the area around the subway station gathers educational, scientific research, entrepreneurial and living Spaces, becoming a typical case of urban functional integration guided by rail transit. These secondary centers are closely connected through a rail system and are no longer isolated functional areas but jointly form Boston's multi-centered and networked urban layout. This spatial form makes the city more balanced in function and also makes rail transit truly an important link connecting innovative activities with daily life.

4. Discussion

The rail transit system in Boston has been continuously improved over the past century, and the formation of its multi-centered structure reflects the trend of urban space towards decentralization. The advantages of this process are not only reflected in alleviating the pressure on the central urban area, but also in promoting the coordinated and sustainable development of the entire city.

Firstly, from the perspective of urban economy, decentralization enables industrial functions to achieve spatial stratification and complementarity. High value-added industries are concentrated in the core area with the highest accessibility, while R&D, production and living services are distributed outward along the track, forming a mutually supportive industrial chain. This structure not only maintains the economic vitality of the central urban area but also enhances the development potential of the peripheral areas, avoiding the risk of "single-core overheating". Second, from a socio-spatial perspective, the expansion of rail transit has effectively reduced commuting costs while broadening residents' housing choices. As accessibility improves, residential demand becomes more spatially dispersed, easing both the shortage and the price pressure in central districts. This pattern of “spatially separate yet temporally connected” living enables urban residents to reside farther from their workplaces without sacrificing connectivity, thereby achieving a more sustainable balance between quality of life and travel efficiency. Third, from an environmental and planning perspective, decentralization encourages a compact, mixed-use urban form supported by the principles of TOD. High-density, multi-functional development around transit nodes reduces reliance on private vehicles, lowers carbon emissions, and improves overall land-use efficiency. Boston's experience illustrates that rail transit should be regarded not merely as a mode of commuting but as a structural instrument for guiding urban transformation. Cities aiming for sustainable growth should define clear functional roles for transit nodes, integrate industrial and housing policies to foster coordinated development within a polycentric system, and maintain infrastructure parity between central and peripheral zones. In doing so, urban planners can mitigate spatial fragmentation, prevent resource concentration, and ensure that public transit becomes a genuine driver of social equity, environmental sustainability, and long-term urban resilience.

5. Conclusion

This study utilizes Boston as a case study to examine how the accessibility of rail transit influences the spatial distribution of urban functions. Based on accessibility theory, decentralization theory, and the Transit-Oriented Development (TOD) model, the research finds that the evolution of Boston's rail transit network has played a significant role in reshaping the urban space and economic patterns. The improvement of accessibility along rail transit lines has accelerated the redistribution of population, industries, and services, thus forming a more balanced multi-centre urban structure. Rail transit nodes, such as Kendall Square, Alewife, and Quincy Centre, have become new functional hubs that integrate life, innovation, and business, demonstrating the synergy between transportation infrastructure and spatial reconstruction. The research results indicate that, under the guidance of efficient transportation planning, decentralisation can enhance economic diversity, improve housing affordability, and promote sustainable land use practices. The experience of Boston shows that rail transit can transform from a transportation system into a structural driving force for urban reorganisation, thereby promoting greater spatial equity and resilience. However, this study also has some limitations. This study mainly relies on qualitative analysis and secondary data, and may not be able to fully capture the dynamic interaction among railway accessibility, land value and population mobility over time. Future research should integrate quantitative spatial analysis and multi-source datasets (such as GIS-based accessibility modeling, big data mobility tracking, and land price monitoring) to gain a more comprehensive understanding of the causal mechanism between public transportation expansion and spatial reconstruction.

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