

Impact of Urban Rail Transit on Business Districts Based on Time Distance: A Case Study of Urumqi Light Rail

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Abstract

Based on the concept of hypercartography, a model is established to convert the time distance of light rail travel into spatial distance measured in meters (m). On this basis, through the map projection spatial transformation method of Geographic Information System (GIS), the converted distance is used to redefine the inter-location distance, deforming the original map to form a time-distance map. By spatializing time distance and utilizing technical means, visual representation of time distance is achieved. The results indicate that the impact of light rail on urban morphology is influenced by the distance of stations from the selected central point, exhibiting greater deformation at greater distances from the center and smaller deformation nearer to the center. The influence of light rail on commercial center layout generally exhibits a concentric zone distribution. Time distance compresses traditional urban morphology. With the advancement of Urumqi's metro construction and the improvement of infrastructure, there remains considerable potential for further compression of time distance within the city, and existing commercial centers should be upgraded. This study provides a new reference and conceptual framework for Urumqi's urban development.

Full Text

Preamble

Impact of Urban Rail Transit on Business Districts Based on Time Distance: Urumqi Light Rail

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Abstract: Based on metacartography, this study establishes a model to convert the time distance of taking light rail to spatial distance in meters. On this basis, this study uses the spatial transformation method of geographic information system (GIS) map projection to redefine the distance between two locations with the converted distance and transforms the original map into a time distance map. By spatializing the time distance, this study gives time distance a visual expression. The results show that the influence of light rail on urban form is affected by the distance between the station points and the selected center point; that is, the transformation is greater when the station points are farther away from the center point, and vice versa. The impact of light rail on the layout of business centers is basically distributed in the shape of a circle. Time distance compresses the traditional urban form. There is still much room for the city to further compress the time distance, and the existing business centers should be upgraded.

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Introduction

The formation of urban business districts is affected by many factors. According to the theory of commercial location [?, ?, ?], the formation of urban business districts mainly takes on combined impacts from differentiated rent mechanisms, market supply and demand mechanisms, and aggregation and diffusion mechanisms. With different rents in different locations in the city and different orientations of different commercial forms, the differentiated rent mechanism affects the choice of business location. The demand of the consumer market determines the development direction of business districts, and the relationship between supply and demand affects the scale and level of these districts. When one commercial scale expands, different forms of business are generated because commercial space is always in the process of agglomeration or diffusion. The formation of business districts has an inseparable relationship with traffic [?, ?]. In the early stage of a city, business districts are distributed along the traffic network, land transportation has limited impact on the city's business districts, and the psychological time of consumers has limited impact on their travel frequency and travel distance. Because rail transit has unparalleled advantages compared with other land-based transportation, such as high-speed and large passenger capacity trains, rail transit affects the reformation of business districts [?]. According to relevant practical development experience and theoretical research, the influence of rail transit on the evolution of business districts is shown in the three aspects of expected effect, reachability effect, and passenger flow effect.

Traffic plays a role in the formation of business districts, but the development of a city faces many issues, such as the rapid expansion of urban areas, rapid growth of motor vehicles, and urban road congestion. Therefore, traffic is an

important problem that affects the quality of residents' lives and must urgently be solved. Urumqi is the political, economic, and cultural center of Xinjiang, the western gateway to the outside world, the bridgehead of the New Eurasian Continental Bridge and the core area of the Silk Road economic zone. Accordingly, Urumqi has seen rapid development in recent years, and urban traffic congestion has gradually increased, with more than 800,000 privately owned cars. The Bus Rapid Transit (BRT) system has completed seven lines and become an important mechanism to meet the public' s transportation needs. However, the BRT must occupy dedicated lanes on the ground and thus cannot be considered a long-term solution for urban traffic congestion. According to the observations from cities with subways or light rail, the construction of rail transit has played a significant role in alleviating transport tension, saving transport time, forming economic integration, promoting the development of a knowledge economy, promoting the development of tertiary industries and tourism, providing employment opportunities, and improving the quality of urban residents' lives. The importance of rail transit includes not only freeing up space on the ground, which was originally narrow, but also shortening the time distance between two locations under the premise of unchanged geographical distance. In particular, a stable transportation system that is not affected by bad weather greatly improves the travel efficiency of an entire city.

Time geography was put forward for the first time by Hägerstrand in a paper published in 1970 [?], which set up unique geography symbol systems such as path and prism. With the development of computers and geographic information systems (GISs), Lenntorp, Martin, Miller, Kwan, and others constantly improved the calculation method of time geography [?, ?, ?, ?, ?, ?]. Time geography is a new development in transport planning, the family and individual level, the urban activity system, time use and management, environmental and public health, and other fields [?, ?, ?, ?, ?, ?, ?]. In recent years, Ellegård and others put forward the concept of "new" time geography [?, ?]. Liu, Kuby, Hadas, and others studied public transportation from the aspects of connectivity and passenger flow volume [?, ?, ?]. There are also studies on the cost of transfer in public transport systems [?]. Ferbrache studied the influence of traffic on urban development from the perspective of cultural approaches to transport geography [?]. Hurst, Kasraian, Sekar, and others studied the impact of the rail transit system on land use and land-use change [?, ?, ?]. The analysis concentrated on North America in three main areas: urban development and land values, health and environmental impact, and socioeconomic factors [?, ?].

The research of time distance in China mainly focuses on the time distance between cities on the meso level. Most of the studies on the time difference inside cities adopt the research method of isochronic circles. For example, Zhu conducted a metacartography study of time distance with the example of the Fuzhou-Shanghai railway passenger transportation system [?]. Zhu also selected the main nodes to study traffic time distance inside Fujian Province [?]. With the continuous evolution of the internal spatial pattern of cities, many scholars also study the distribution of urban traffic' s isochronic circles through time cost.

For instance, Zeng, Chen, Zhao, and Huang divided the cities of the Macao Special Administrative Region, Guangzhou, and Shenzhen into time units and selected two-way links between the main nodes and the city center to research the isochronic circles of transport [?, ?, ?, ?]. Throughout the literature on time distance within cities, most scholars have focused on drawing isochronic circles of travel as the single presentation method but have rarely combined it with time distance mapping.

In the following, we use a novel method of calculation to show the effect of the light rail on the time distance within the city. We try to represent the contraction of space distance in an intuitive way. The aims of this study are to provide a reference for commercial location choice in the future and predict for residents' travel. First, a time distance map is produced by space transformation of time distance. Second, we analyze the effect of this contraction on the urban pattern and business circle. Finally, the applicability and limitations of this method are discussed.

Planning of the Urumqi Light Rail and Business Districts

Planning of the Urumqi Light Rail

The downtown area of Urumqi is surrounded by mountains to the east, west, and south. The terrain of Urumqi is high in the southeast and low in the northwest. Its urban construction is distributed in a narrow pattern in a north-south direction. Urumqi Urban Rail Transit plans to build seven lines with a total length of 211.9 km [?]. The recent construction plan intends to implement Line 1, which has a length of 26.5 km and a total of 21 stations, in advance. Line 2 in the first phase has a length of 21.4 km and consists of 16 stations with a total construction length of 44.4 km; the total investment of the project is 31.2 billion RMB. The plan intends to form the basic framework of a rail transit network to meet the recent growing traffic demand and guide and promote the coordinated development of the regional economy. When the basic network structure is formed, rail transit passengers will account for 10-14% of the total public transport passengers in 2020. The first phase of the rail transit construction is Line 1, with a planned total duration of 7.5 years; the planned construction period is from 2012 to 2016, and the trial operation of the entire Line 1 will occur in 2018. The first phase of the civil engineering project of Line 2 began after the completion of the civil engineering project of Line 1, and the planned total duration is 6.5 years; Line 2 should be complete and ready for operation in December 2020. The first phase of the civil engineering project of Line 4 began in early 2016, with a planned total duration of 7 years; Line 4 should be ready for operation at the end of 2020 [Figure 1: see original paper].

Planning of the Urumqi Business Districts

The planning of the Urumqi business system mainly includes international business centers (including the Main International Business Centre and the Interna-

tional Business Subcentre), urban business centers, municipal business centers, regional business centers (city sub-centers), community-level business centers, and feature business streets. According to the overall urban planning and commerce and trade development orientation of Urumqi [?], Urumqi business will form an overall development pattern of “two cores, nine hearts, sixteen districts, multiple streets and multiple points.” Two cores: the cores of urban business development are constituted by the Main International Business Centre and the International Business Subcentre and mainly encompass Xinjiang, the entire country, and central and western Asia. Nine hearts: the nine business clusters consist of two urban centers and seven municipal business centers that mainly serve the city of Urumqi and the surrounding areas. The two urban business centers are the Exhibition Business Centre and the High-Speed Rail Business Centre; the seven municipal business centers are the Nanhu Business Centre, the Railway Bureau Business Centre, the South Railway Station Business Centre, the Hongshan Business Centre, the Gumudi Business Centre, the North New District Business Centre, and the South Business Centre. The “two cores” and “nine hearts” —a total of 11 business districts—are included within the scope of this research paper. Sixteen districts: the 16 business cluster areas that involve regional business centers mainly meet regional residents’ demand for the goods that they consume. Multiple streets: by exploring culture and folk resources and emphasizing these characteristics, 33 business streets are formed to lead in a modern business fashion. Multiple points: in focusing on community-level business centers, business cluster areas are formed according to residence and population distribution to meet community residents’ demand for the goods that they consume. The “16 districts,” “multiple streets,” and “multiple points” are business outlets that meet the needs of regional and community residents; because of their small range of application, they are not included within the scope of this research paper [Figure 2: see original paper].

Research Methods and Data Sources

Research Methods

This study’s research method is based on the basic idea of metacartography [?]. In 1953, Hägerstrand, from the Department of Geography of Lund University in Sweden, first proposed the term metacartography [?, ?, ?, ?, ?]. Based on metacartography, this study adopts the space transformation of time distance to build a model to convert the time distance of light rail rides into spatial distance in meters. Through the space transformation method of GIS map projection, we use the converted spatial distance to redefine the distance between two locations and transform the original map into a time distance map. Based on this time distance map, we visualize on the map the spatial compression that is caused by the intracity traffic time compression [?, ?].

Data Sources

In this paper, the city center is defined as the time from the center of South Gate to various end points. South Gate is the old city center of Urumqi and is located in the main international business district—in one of the “two hearts.” South Gate is a landmark site of Urumqi, and the autonomous regional government is distributed near it. Since ancient times, South Gate has been Urumqi’ s commercial, cultural, and financial center; thus, South Gate is selected as the compression center of this study. As early as the 1920s, the Nanguan area south of South Gate formed a business street, and the Shidazi area in the north not far from South Gate was the business center of Urumqi. There were human markets, horse markets, day markets, night markets, shops of merchants of various nationalities, and trading companies of Russian merchants. Since the reform and opening up, especially recently, the business district of South Gate has been further expanded. In 2003, the International Bazaar began to operate, and it became Urumqi’ s business and tourism center with increasingly more guests from around the world. The number of visitors reached 671,000 in July 2016, with a daily number of more than 33,000 people who arrived mainly on public transport [?]. It is difficult to park a car and obtain car rides near the International Bazaar, and traffic congestion is very severe, which to some extent affects tourists’ choice of transportation to the International Bazaar [?].

The design speed of light rail is 80 km/h. However, considering the acceleration and deceleration between stations, the actual travel speed is lower than the design speed. The performance and standards of subways and lines in the metro cities in China, such as Shanghai, Beijing, Nanjing, Shenzhen, and Hangzhou, are a maximum speed in operation of 80 km/h and an average speed of generally 30–40 km/h. Therefore, this paper uses 40 km/h when calculating the speed of light rail and assumes that the average time length of a stop at each station is 40 s [?]. This paper’s light rail plan originates from the Urumqi Rail Office (Urumqi City Rail Group). The research area includes the downtown region of Urumqi, with an area of 1,435 km². The downtown area comprises the eight functional areas of the Tianshan District, Shayibak District, Hi-tech District (New Urban Area), Shuimogou District, Midong District, Economic Development District (Toutunhe District), and North New District. In the north, the downtown area borders Wuyi Farm, Anningqu Township, Gumudi Township, and the Lucaogou Township administrative boundary. In the south, the downtown area borders the administrative boundary of the Tianshan District. In the east and west, the downtown area borders the outer ring of the planned highway. The downtown area also includes the section of Changji City (which is located northwest of Urumqi) that is covered by light rail.

Results

Time Distance Calculation and Conversion

According to a formula, we calculate the time distance from South Gate to the end of each line (time to arrive at destination) . The time and distance reserves two decimal fractions while computing. To give the space compression of time distance a more intuitive expression in the map, we use the actual speed of a city car, 20 km/h, as the reference speed. To compare time distance and actual space distance, we convert the time to arrive at a station to the time distance in meters. The calculation method is [?]:

$$DT_i = DS_0 \times \frac{T_i}{T_0} \quad (i = 1, 2, 3, \dots, n)$$

where DS_0 = car-driving distance between two locations in the city; and T_0 = average required time for DS_0 . Therefore, DS_0/T_0 is the actual car speed in the city. After conducting on-site tests with taxis at different times in the city, we set this value at 20 km/h. DT_i is the space conversion result of the time distance from South Gate to each destination, and T_i is the time from South Gate to each station. To more intuitively show the trend of the narrowing time distance of intracity traffic after the completion of the light rail and to reasonably compare time distance with space distance, we calculate the time distance between the South Gate station and each station after the formation of all light rail lines according to the formula .

Time Distance Map Making

We use locations i and j as examples. The geographical coordinates of the two locations are (x_i, y_i) and (x_j, y_j) , respectively. The time distance that is formed by a given traffic pattern is T_{ij} , and the space conversion result of the time distance is DT_{ij} . The mathematical process for the visualized expression is as follow [?].

The vector is $\mathbf{a}_{ij} = (x_j - x_i, y_j - y_i)$. The direction vector is $\mathbf{e}_{ij} = \left(\frac{x_j - x_i}{\sqrt{(x_j - x_i)^2 + (y_j - y_i)^2}}, \frac{y_j - y_i}{\sqrt{(x_j - x_i)^2 + (y_j - y_i)^2}} \right)$. With i as a starting point, \mathbf{e}_{ij} as the direction vector, and the norm of the vector as DT_{ij} , we can determine the time distance $j'(x'_j, y'_j)$ from location j to the actual location i . The line segment between i and j' in the map is the time distance between the two points. The previous step forms the corresponding relationship of j and j' . Now we can use the Rubbersheet method of the ArcGIS software to stretch the map layers with j as the starting point and j' as the ending point. By repeating the previous operation, we obtain a time distance map [FIGURE:3, FIGURE:4]. In [Figure 3: see original paper], the starting points of the vectors on the original light rail sites and the end of vectors to the displacement of position are shown.

Analysis of the Spatial Transformation Results of the Time Distance

Overall, the time and the spatial distance maps have varying degrees of compression. Northwest of the central point and Lines 3 and 7 in the north of the city have a greater degree of and more obvious compression. The terminal stations of Lines 1-3 in the south are Santunbei, the Border Control Bureau, and No. 12 Middle School. Northeast and southeast of the research scope have a smaller degree of and less obvious compression. Several business districts have changed location and shape. It is worth noting that because stations are selected as only the center of gravity during the mapping process, namely, that the “surface” is converted to a “point,” this time map can represent only the characteristics of space-time compression, not all the points’ actual time distance.

Discussion: Analysis of the Influence of Light Rail on the Urban Structure and Business Districts

Based on the time distance map and Urumqi’ s business districts, this paper analyzes the light rail’ s influence on the study area after its completion.

Analysis of the Light Rail Stations

The actual distance between each station and the center point is D_i , and the converted time distance of each station is DT_i . This paper establishes the relationships among D_i , DT_i , D_i , and $D_i - DT_i$ and conducts linear fitting. The relationship between D_i and DT_i is $y = 0.6768x$ [Figure 5: see original paper]. We find that with an increase in the distance from the stations, DT_i shows a significant linear increase, which indicates that the stations that are closer to the center still have a traffic advantage, but not all DT_i increases with an increase of D_i . Some individual stations improve traffic accessibility with the light rail. The relationship between D_i and $D_i - DT_i$ is $y = 0.3232x$ [Figure 6: see original paper]. With an increase in the distance from the stations, $D_i - DT_i$ also shows a significant linear increase, which indicates that the light railway plays a more obvious role when improving the traffic accessibility of the stations that are far away from the center, but we cannot rule out the more obvious advantages of some points. $(D_i - DT_i)/D_i$ is the compression ratio. This ratio fluctuates and compresses approximately 35% in the end [Figure 7: see original paper], which shows that the compression degree of the time distance has no obvious linear relationship with the actual distance but reaches a stable value in the end.

This result occurs because some stations are affected by the number of transfer stations and can only be reached after two transfers, and some stations can only be reached after multiple stops, which requires more time than driving cars, and the time that is saved by the light rail is offset. However, the light rail has the advantage of not being affected by bad weather, traffic jams, parking problems, and other uncontrollable factors. Thus, the comparison here is only relative and does not mean that the traffic around these sites is deteriorating.

Analysis of the Influence and Regularity of the Business District Pattern

The existing pattern of business district distribution is the point-axis distribution along the roads. Traffic nodes tend to form large business centers and spread out from the center point in circle layers. We use the hierarchical cluster method of SPSS software (Fig. S1). The stations are divided into six levels based on the compression distance. The International Main Business Centre, the International Business Sub-Centre, the Hongshan Business Centre, the Railway Station Business Centre, and Nanhu Business Centre are located in the traditional business district. The Exhibition Business Centre, Railway Bureau Business Centre, and High Speed Rail Business Centre are on the second level, and Gumudi Business Centre is on the third level. There are no business centers in the fourth and fifth levels. Because of the integration of Urumqi and Changji City, Changji is also planned to connect to Urumqi through light rail in the future [?]. As a result, Changji is treated as a special business center and is on the sixth level. The distribution of traditional business districts spreads out according to the shape of the traffic roads. The leveled distribution of new business districts is basically consistent with the leveled distribution of land transportation methods. However, certain individual stations are bypassed. These stations are located on the edge of business centers or are on the borderlines of multiple business centers, which pull on the business districts that they belong to. Some business districts extend to or overlap with the business districts at a higher or lower level, which causes internal division (e.g., the Exhibition Business Centre and the International Business Subcentre). The formed subdistrict becomes another core of this business center or a new business center itself [Figure 8: see original paper].

The survey data show that within urban areas, the average travel time with a bus is 31 min, with a car is 27 min, and on foot is 20 min. In the current situation, the travel distance of most residents is approximately 4-5 km and is considered short-range travel [?]. After the completion of the light rail, the time distance will shorten, which will expand the scope of residents' activities and affect residents' decision-making regarding travel. Time distance will replace the traditional travel distance to become the new standard to measure residents' travel. Leaving a residence to shop in distant business districts will be less dependent on land traffic congestion, but the distance will be calculated with the number of "stations." The central business districts will be further strengthened, and new business districts will be more easily developed in the areas with a greater compression of the time distance.

The areas around transfer stations are more conducive to the formation of business centers. By investigating several business centers, we find that the light rail stations are undoubtedly located at these business centers or on the edge of them or are crossovers that form transfer stations; transfer stations enhance the flow of people at these business centers and promote the improvement of business districts. Areas with intensive transfer stations are more likely to form

large business centers. Combined with the level of compression, we analyze and predict that the areas that are near certain stations will form potential business centers in the future as follows. No. 12 Station is located at the airport, which is between Urumqi and Changji. A near-port business center will be created here to develop a near-port business district. Stations No. 23, 80, 112, 17, 19, and 20 are located north of the city to serve the population and the functional transfer of the old city. Large residential areas will be formed here in the future, and if the government relocates these areas, the development of business districts will be further promoted.

Influence of the Urban Spatial Layout and a Countermeasure Analysis

In the entire research area, the north, northwest, and east of the city demonstrate more obvious compression, whereas the south is not compressed, which is consistent with the recent urban planning concept of Urumqi, namely to “connect in the east, deepen in the west, control in the south and expand in the north.” The business centers in the downtown area still have unparalleled regional advantages; however, convenient transportation increases the competition among business districts. The main business districts in Changji will compete with the Urumqi city area after the light rail transformation, which will shorten the distance between the two cities and is consistent with the regional policy of “integrating Urumqi and Changji.” The South Business Centre in the south of the city is building a maglev to connect to the downtown area. This maglev will greatly enhance the connection between the southern region and the downtown area. The North New District Business Centre in the north of the city does not have light rail stations; bus connection to the closest light rail stations should be added and increased in this area, and light rail planning in later planning stages should increase the extension of nearby lines.

Research with time distance mapping provides a new way of thinking of business district analysis. Time distance mapping can verify the existing business districts or the business districts with future development potential and predict the locations of new future business districts. From the time distance map of Urumqi, we can tell that the areas along the light rail will become an important direction of urban expansion because they provide new space for urban development. Consequently, the pattern of Urumqi urban land use will be changed; the formation and development of new business cores, residential spaces, and industrial agglomeration areas will affect the space layout, development strength, and economic efficiency of the entire city’s land use. Convenient light rail transportation improves the exchange of information between the areas along the rail lines and the downtown area. The construction of light rail will have an impact on how urban residents perceive space. Behavioral geography’s study on spatial perception does not replace the analysis of land use’s functional and social aspects, but it provides another interpretation of the relationship between man and his environment; it supplements the analysis of urban land use’s functional and social aspects [?]. Because the impact of various behavior

constraints changes the output of the impression structure, the completion of light rail will have a structural impact on residents' travel time perception; light rail will expand residents' activity space, increase their travel frequency, and shorten the travel time distance in terms of their intended space.

Conclusions

This study is illustrated by the example of Urumqi, and also has reference significance for the other cities that are building light rail.

Between different levels of business districts: (1) Business districts are centered in the downtown area and distributed in circular shapes. The central business districts will be strengthened. Downtown business districts still have a regional advantage; considering competition, they should upgrade their service industries and develop different forms of business in combination with light rail stations, such as underground shops. (2) The districts on the edge will produce a centripetal force because of a shortened time distance. Light rail construction will greatly promote the development of business districts on the edge of business districts; these areas should improve their internal service industries to attract passengers.

Micro level within the specific business districts: (1) Some business districts will encroach on adjacent business districts, and business districts will have internal differentiation. (2) New traffic nodes will form around transfer stations, the flow of people will increase, and the original business center layout will demonstrate micro changes. (3) Business centers that do not have light rail access should strengthen their connection with the surrounding bus stations to compensate for their traffic disadvantages.

This study has several limitations. First, because the research scale covers the city and surrounding area, some areas' time and spatial distances do not show obvious compression on this scale. Second, in the time distance mapping, the selected stations represent a certain area, but the number of sample "points" depends on the light rail stations. The obtained time distance map can only represent time and space compression, not the actual time distance of all points. Third, this study selects the South Gate station in the old city as the center point of compression; the new city planning proposes the building of double centers. If the research is continued, it can select a second compression point to observe the influence of the railway transportation business center. Fourth, because this study targets the time-space compression that light rail causes on urban traffic, it does not conduct an in-depth study on other transportation methods and the areas without light rail access. Fifth, this article is based on group research. Kwan et al. developed a geographical narration method based on GIS in the application of spatial and temporal behavior research, which took a behavior main body as its object to analyze its daily travel behavior. It fused qualitative analysis such as social culture and subjectivity [?, ?, ?, ?]. With the progression of the Urumqi subway construction process and the improvement

of infrastructure, there is still much room for the further compression of time distance within the city. More feature differentiation with “space distance” will appear; the distribution of the urban population and business districts will also demonstrate new characteristics. We hope that these new features will attract further attention and research commitment from more geographers.

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Supplemental Data: Fig. S1 is available online in the ASCE Library (www.ascelibrary.org).

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