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Evaluation of Spatial Accessibility and Dynamic Regeneration of Industrial Heritage from the Perspective of the Continuity of Historical and Cultural Cities—A Case Study of Handan City

Xin Liu * and Feihua Yuan

School of Architecture and Art Design, Hebei University of Technology, No. 29 Guangrong Road, Hongqiao District, Tianjin 300130, China; 202422301015@stu.hebut.edu.cn
* Correspondence: liuxin@hebut.edu.cn; Tel.: +86-13820185173

Abstract

Handan's industrial heritage flows from the history of the ancient capital into modern industrial civilization, serving as a vital medium for urban transformation and the preservation of the city's cultural legacy. However, constrained by inadequate transportation infrastructure and insufficient integration with historical resources, this industrial heritage exhibits low accessibility and limited development potential. From the perspective of the continuity of the historical and cultural city, this study aims to evaluate the accessibility characteristics of industrial heritage in Handan. Based on road network data, industrial heritage POIs, and the cultural relics protection units of POIs, the GIS network analysis method is employed to assess the overall accessibility of various transportation modes within Handan. Subsequently, from a micro-network perspective, it measures and analyzes both the road network accessibility of the industrial heritage sites and the accessibility between individual heritage sites. The findings reveal that the accessibility of Handan's industrial heritage follows a "central–peripheral" hierarchical pattern. The central urban area and the Fengfeng Mining District demonstrate strong short-term coverage capacity and superior accessibility, whereas the western mountainous region exhibits relatively low accessibility due to topographical constraints. The accessibility potential of the eastern road network remains difficult to translate into synergistic advantages. Accordingly, a multi-level adaptive strategy for zoned conservation and regeneration is developed, providing a spatial analytical basis for the dynamic regeneration of industrial heritage and the coordinated conservation of historical and cultural resources.

Keywords: industrial heritage; accessibility; GIS network analysis method; Handan city; historic and cultural city

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1. Introduction

Industrial heritage serves as an important carrier of industrial civilization [1], bearing witness to the socio-economic, engineering, technological, and cultural developments of cities during the industrial era [2] and constituting an indispensable part of a city's historical continuity and unique cultural identity [3]. The preservation and adaptive reuse of industrial heritage has become a key issue in urban renewal efforts across China. Revitalizing existing industrial heritage sites and ensuring their sustainable utilization represent a crucial direction for fostering a distinctive urban character. The state encourages the exploration of the diverse values inherent in industrial heritage and promotes its

integration into urban life, thereby facilitating the translation of these values and the continuity of cultural heritage.

Handan's industrial heritage boasts a profound historical foundation and distinctive contemporary characteristics. Together with the Zhao culture, the Cishan culture, and the Northern Qi grotto culture, it forms a "three-thousand-year uninterrupted" civilizational epic [4], serving as a witness to the industrial revolution spanning from ancient handicrafts to modern large-scale machine-based production. As a key city designated under the Soviet Union's "156 Major Projects" initiative, Handan is home to iconic industrial landmarks such as the Handan Miansan Textile Industrial Heritage Site [5]. Coal mining, steel production, textiles, and ceramics constitute the core categories of Handan's industrial heritage [6]. This heritage not only bridges the gap in industrial memory between the ancient Zhao culture and the modern urban landscape but also complements historical sites across time, providing unique resources for Handan's cultural and tourism transformation. Handan was designated as part of the third batch of "National Historical and Cultural Cities" [7], establishing a tiered and categorized protection system. As a "city that has never changed its name for three thousand years," Handan's historical narrative is fully embedded within its urban spatial fabric. For a city with such rich historical depth, overlooked industrial heritage can, in fact, reveal its unique value.

Although Handan possesses a dual heritage framework combining "ancient historical heritage" and "modern industrial heritage," these two heritage types developed in isolation, with Handan's industrial heritage not yet fully integrated into the primary conservation framework for this historic and cultural city. The traditional protection methods have overlooked the dynamic vitality of industrial heritage as a carrier of urban memory. How to shift the transformation of industrial heritage from "static preservation" to "dynamic regeneration" has become a key focus of urban sustainable development. It requires urban renewal to activate internal cultural and social functions while continuing the physical texture of historical space, and to shift toward memory activation and collaborative governance [8]. As a pivotal turning point in the city's developmental trajectory, industrial heritage serves not only as a bridge for historical continuity but also as a crucial element in preserving the city's historical integrity [9]. The conservation of industrial heritage and that of the historic and cultural city can be pursued simultaneously. However, there are three profound interconnections between Handan's conservation framework for the historic and cultural city and its industrial heritage: First, the two are complementary in terms of heritage types, with the intervention of industrial heritage enriching the historical and cultural connotations of historical and cultural cities [10]. Second, they are adjacent in spatial distribution, forming landscapes where civilizations from different historical periods overlap. Finally, they complement each other in spatial form, with the large-span buildings of industrial heritage contrasting with the traditional courtyards of historical districts, providing a more diverse spatial carrier for subsequent functional replacement and revitalization. However, this potential correlation has not been effectively linked in reality, and the complementarity in types has not been transformed into an experiential route; spatial proximity does not equate to actual accessibility. Therefore, the introduction of accessibility measurement to quantify the actual spatial connectivity between the two will transform the potential correlation into spatial accessibility and continuously perceivable experiences and achieve the dynamic regeneration of industrial heritage.

A large number of industrial heritage sites in Handan have prominent problems such as scattered locations, poor transportation connectivity, and insufficient connections with historical and cultural resources. These issues not only hinder the revitalization of the industrial heritage itself but also damage the overall spatial appearance and integrity of the historical and cultural city. By employing accessibility analysis, it is possible to clar-

ify the spatial relationships between industrial heritage sites and various historical and cultural resources, integrate industrial heritage into the city's comprehensive conservation framework, construct a coherent urban historical narrative, and seamlessly connect disparate historical fragments across time and space. This approach not only leverages complementary strengths but also fosters synergistic effects, enhancing the conservation efficacy of all types of heritage and amplifying the region's cultural influence. As a result, these industrial heritage sites can truly become an organic and dynamic part of Handan's historic and cultural urban fabric.

The study of the accessibility of industrial heritage provides a crucial reference for achieving the protection and reuse of industrial heritage. Accessibility is a quantitative expression of people's desire and ability to overcome obstacles such as distance and time to reach service facilities or activity venues [11,12]. Accessibility studies abroad have been widely applied across multiple fields, including poverty, healthcare, urban public facilities, transportation planning, and land use [13–17]. Domestic research has primarily focused on the accessibility of physical spaces; to date, most studies have concentrated on the measurement and evaluation of geographic spatial accessibility. These studies tend to focus on the accessibility of urban service facilities such as healthcare and green spaces as well as cultural heritage [18–21]. However, there is relatively little research on the accessibility of industrial heritage. In addition, existing research mostly focuses on evaluating the accessibility of heritage sites in urban transportation networks, with insufficient attention paid to the accessibility between heritage sites. Especially in the context of protecting historical and cultural cities, there is still a need for further exploration of how to comprehensively examine road network accessibility and the accessibility between heritage sites.

Therefore, this study takes the industrial heritage of Handan as the research object and summarizes the spatial distribution characteristics of Handan's industrial heritage. Working from the perspective of the continuity of historical and cultural cities, we will construct a multidimensional accessibility evaluation framework. Utilizing network analysis, we measure the overall accessibility of industrial heritage in each county and district, as well as the accessibility of industrial heritage road networks and accessibility between heritage sites, from both the urban perspective and the perspective of micro-industrial heritage sites. The aim is to systematically evaluate the accessibility characteristics of Handan's industrial heritage within the context of a historical and cultural city and to provide targeted accessibility optimization strategies and spatial activation suggestions for the protection and renewal of industrial heritage.

2. Materials and Methods

2.1. Study Area Overview

Handan City is located at the southernmost tip of Hebei Province. It is bordered by the Taihang Mountains to the west, adjoins the North China Plain to the east, and shares borders with the provinces of Shanxi, Shandong, and Henan. Known as the "Capital of Idioms" and the "Hometown of Taiji," it is a regional central city approved under the "Outline of the Beijing–Tianjin–Hebei Coordinated Development Plan" and the "Central Plains Economic Zone Plan." Handan's industrial heritage primarily developed from the late 19th century to the mid-20th century, particularly during the "First Five-Year Plan" and "Second Five-Year Plan" periods following the founding of the People's Republic of China.

This study takes the administrative area of Handan City as the research scope and takes industrial heritage with clear industrial historical value and verifiable sources as the research objects. The selection criteria follow the following principles: First, the industrial heritage site must be on the industrial heritage lists published by national, provincial, and municipal government departments, as well as industrial heritage included in the

proposed list of municipal industrial heritage for protection. Second, the site or object must have significant historical value in industrial development, including industrial heritage related to the "156" Projects aided by the Soviet Union. Third, the historical evolution and spatial information must be verifiable through literature and local sources. Fourth, the spatial points must be accurately located and matched with road network data for accessibility analysis.

Based on the above principles, the collected industrial heritage data was sorted, verified, and deduplicated, and ultimately fourteen industrial heritage sites that met the inclusion criteria of this study were selected. The sample covers industrial heritage that meets the selection criteria from existing official lists, the proposed recognition list, and relevant historical documents, which provides a research basis for the accessibility evaluation of industrial heritage in Handan. These sites include one provincial-level industrial heritage site, five municipal-level industrial heritage sites, two industrial heritage sites related to the Soviet-aided "Project 156," and eight municipal-level industrial heritage sites under proposed recognition. Among these, there is one modern textile site, one steel industry site, three coal industry sites, one coal washing and processing site [22], two modern brewing industry sites, three revolutionary military heritage sites, one ancient ceramic site, and two ancient metallurgical sites (Table 1).

Table 1. Types of industrial heritage in Handan.

Order Number	Name	District/County	Type
1	Handan Miansan Textile Industrial Heritage Site	Congtai District	Modern Textile Industrial Heritage
2	Congtai Liquor Site Museum	Congtai District	Modern Brewing Industry Heritage
3	Former Site of the 129th Division Arsenal of the Eighth Route Army, Huatuo Village, Ci County	Ci County	Revolutionary Military Industrial Heritage
4	Hangang Industrial Heritage	Fuxing District	Modern steel industry heritage
5	Former Site of Tong'er Mine	Fengfeng Mining District	Modern Coal Industry Heritage
6	Cizhou Kiln Site	Fengfeng Mining District	Ancient Ceramic Industrial Heritage
7	Ancient Iron Smelting Furnace in Kuangshan Village	Wu'an City	Ancient Metallurgical Industrial Heritage
8	Xida Ordnance Factory Industrial Heritage Site	Shexian County	Revolutionary Military Industrial Heritage
9	Cuilu Iron Smelting Site	Wu'an City	Ancient Metallurgical Industrial Heritage
10	Former Site of Lianggou Arsenal	Wu'an City	Revolutionary Military Industrial Heritage
11	Daming's Centennial Cellar Brewery	Daming County	Modern and Contemporary Brewing Industry Heritage
12	Shenjiazhuang Coal Mine	Ci County	Modern Coal Industry Heritage
13	Former Site of Liuhe Coal Mine	Ci County	Modern Coal Industry Heritage
14	Fengfeng Matou Coal Preparation Plant	Fengfeng Mining District	Modern Coal Washing and Processing Industrial Heritage Site

2.2. Data Processing and Sources

In response to the possible differences in coordinate systems, data formats, spatial scales, and attribute structures among data from different sources, we carried out unified coordinate transformation, spatial matching, and attribute organization for relevant data.

2.2.1. Industrial Heritage Data

Based on the list of industrial heritage sites in Handan City obtained from provincial and municipal government authorities and the list of cultural relics protection units in Handan City compiled from the National Cultural Heritage Administration's statistics of nationally protected cultural heritage sites, POI data for Handan's industrial heritage sites and its cultural relics protection units were retrieved from Baidu Maps. The research combined data with field investigation to verify the spatial locations and current conditions of some industrial heritage sites to establish a spatial database for industrial heritage [23].

2.2.2. Road Network Data

Road network data is an essential component for connecting industrial heritage sites with cultural relics protection units, and it directly impacts the accuracy of accessibility analyses for industrial heritage sites. The road data for this study was primarily sourced from OpenStreetMap [24–26]. Administrative division maps were obtained from the National Geographic Information Public Service Platform. These data were used to extract and construct a map of Handan City's main road network (Figure 1). Based on road classification methods, the road centerlines were identified to build a road network dataset. Travel time was used as the impedance for the road network [27].

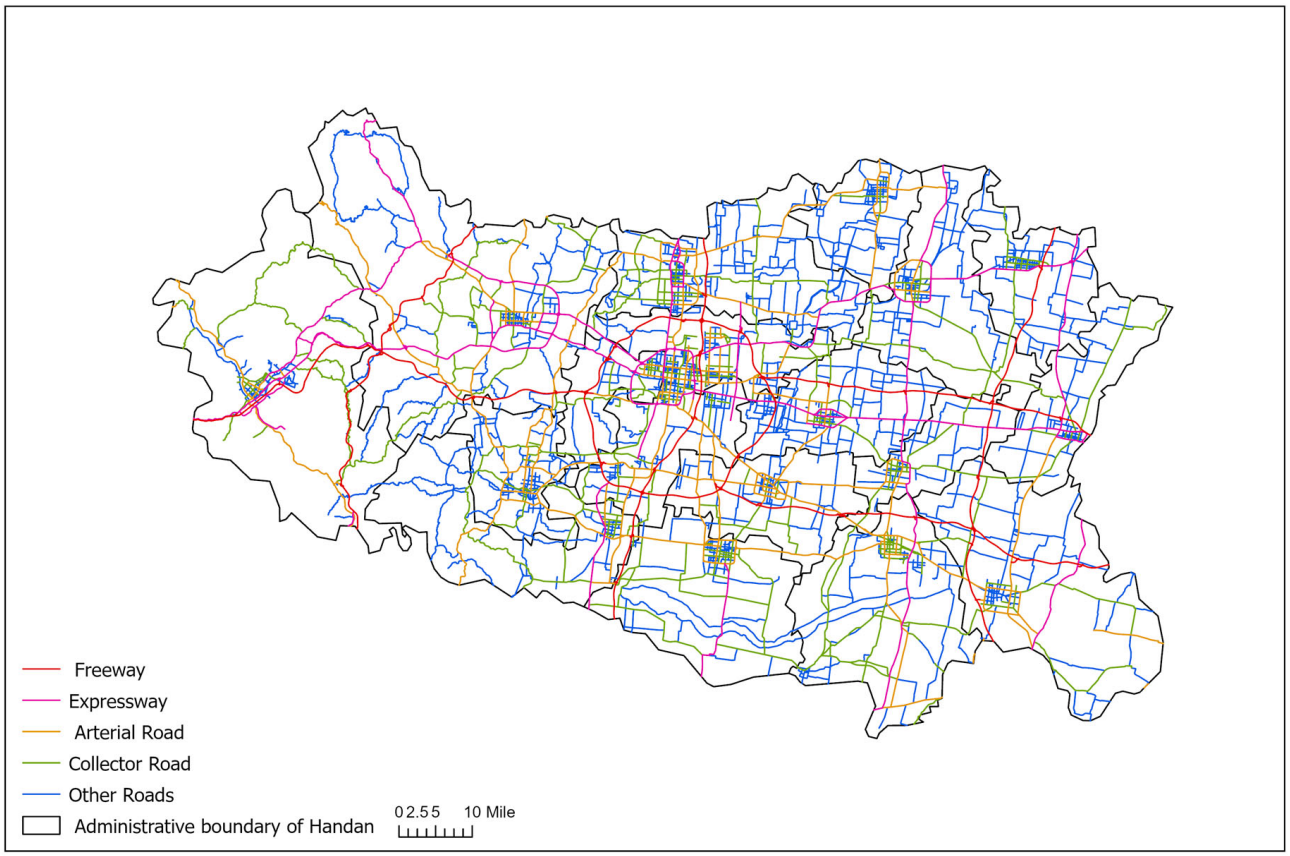


Figure 1. Major road network map of Handan City.

Referring to the Code for Design of Urban Road Engineering (CJJ 37-2012) and various literature on design speed, the vehicle speeds for freeways, expressways, arterial roads, and collector roads are set at 110, 80, 60, and 45 km/h, respectively. The cycling speed is set at 15 km/h [28], which refers to the common speed range and relevant literature for urban leisure cycling and moderate intensity commuting cycling, and here reflects the average movement level of general cyclists in the urban road network.

2.2.3. Population Raster Data

The population raster data for Handan City was obtained from the WorldPop global population database (Figure 2) and has been used in subsequent calculations to determine the number of people served by industrial heritage services as well as the population coverage rate.

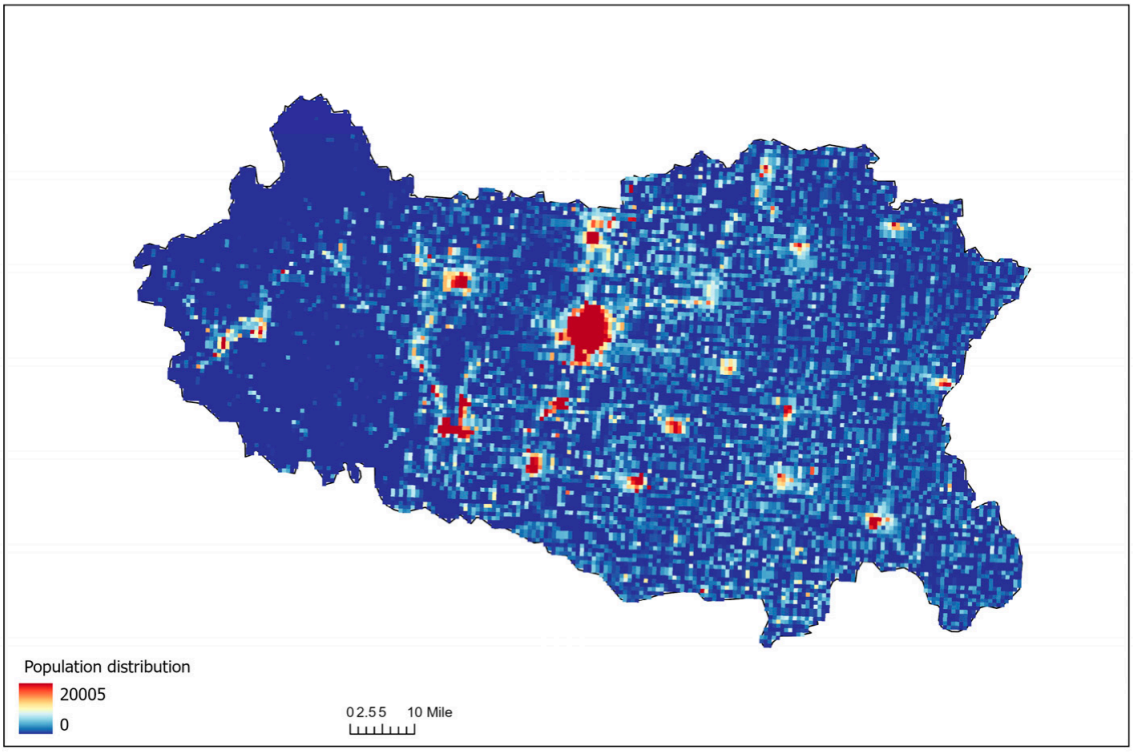


Figure 2. Population distribution raster map of Handan City.

2.3. Research Approach

Based on the analysis of the spatial distribution characteristics of industrial heritage in Handan and its spatial relationship with historical and cultural protection units, the GIS network (ArcGIS Pro 3.1.5) analysis method is applied. At the city level, the overall accessibility is characterized by the proportion of accessible area and population coverage of industrial heritage. At the heritage level, accessibility is comprehensively evaluated based on road network accessibility and accessibility between heritage sites. Furthermore, based on regional accessibility differences and types of industrial heritage, differentiated collaborative development strategies are proposed.

2.4. Research Methods

2.4.1. Overall Accessibility Evaluation Method

In this study, the service area and the population served are used as evaluation indicators for the overall accessibility analysis. The network analysis method is employed to examine the accessibility of industrial heritage sites by car and bicycle. The accessibility of industrial heritage sites across various districts and counties is assessed using the accessible area ratio and the population coverage rate [12].

The accessible area ratio refers to the proportion of the accessible area of industrial heritage sites within a specific time threshold relative to the total area of the county or district [29,30]. Population coverage rate refers to the proportion of the population served by a service area relative to the total population of the county or district [31,32].

2.4.2. Evaluation Method for Road Network Accessibility

Using fourteen industrial heritage sites within the municipal area as starting points and various intersections as destination points, an OD cost matrix analysis based on network analysis methodology is employed to represent the accessibility of each industrial heritage site to all other intersections using the weighted average driving time [33,34]. The average shortest driving time from each intersection within the study area to the industrial heritage sites is adopted as one of the evaluation indicators for the accessibility of the industrial heritage road network. This approach provides a relatively realistic and objective measure of the transportation costs associated with industrial heritage sites from the perspective of a historic and cultural city. The calculation formula is as follows:

$$T_{R,i} = \sum_{i=1}^{n} t_{ij}/n \quad (1)$$

where $T_{R,i}$ denotes the average driving time from each intersection to industrial heritage site i; t_{ij} denotes the shortest driving time from the j-th intersection to industrial heritage site i; and n represents the number of intersections within the study area.

The road network accessibility coefficient is a value derived from the calculation of the shortest driving time from an industrial heritage site to each intersection. It represents the ratio of the average driving time for that industrial heritage site to the average driving time for all industrial heritage sites within the study area. The calculation formula is as follows:

$$A_{R,i} = T_{R,i} / \left(\sum_{i=1}^{n} T_{R,i}/n \right) \quad (2)$$

where $A_{R,i}$ denotes the road network accessibility coefficient for industrial heritage site i; $T_{R,i}$ represents the average shortest driving time from each intersection to industrial heritage site i; and n is the number of industrial heritage sites within the study area. A smaller value of $A_{R,i}$ indicates better road network accessibility whereas a larger value indicates poorer road network accessibility.

The road network accessibility coefficient ranges from 0 to 2, with a mean value of 1. A value greater than 1 indicates that the road network accessibility of this industrial heritage site is lower than the average accessibility across all industrial heritage sites within the study area. A value less than 1 indicates that the road network accessibility of this industrial heritage site is higher than the average accessibility across all industrial heritage sites within the study area.

2.4.3. Evaluation Method for Accessibility Between Heritage Sites

This study integrates industrial heritage sites and cultural relics protection units into a network-based assessment framework. As a city with a diverse and layered historical and cultural heritage, Handan's heritage system encompasses Zhao culture sites, remnants of the ancient Ming-Qing-era city, and modern and contemporary industrial heritage sites. The objectives of the city's conservation efforts require the coordinated revitalization of these heritage assets from different historical periods. This indicator aims to determine whether industrial heritage can be seamlessly integrated into the existing cluster of historical and cultural resources, thereby facilitating the synergistic development of both ancient and modern heritage sites.

Using fourteen industrial heritage sites within the municipal area as starting points and all heritage sites (including both industrial heritage sites and cultural relics protection units) as destinations, an OD cost matrix analysis based on network analysis methodology is employed. The accessibility from a given industrial heritage site to all other industrial

heritage sites and cultural relics protection units is represented by the weighted average driving time. The average shortest driving time from each heritage site within the study area to the industrial heritage sites is used as one of the evaluation indicators for the accessibility between heritage sites. This approach provides a relatively realistic and objective reflection of the transportation costs between industrial heritage sites and other heritage sites from the perspective of a historic and cultural city. The calculation formula is as follows:

$$T_{H,i} = \sum_{i=1}^{n} t_{ij}/n \tag{3}$$

where $T_{H,i}$ denotes the average driving time from each heritage site to industrial heritage site i; t_{ij} denotes the shortest driving time from the j-th heritage site to industrial heritage site i; and n represents the total number of other heritage sites within the study area.

The accessibility coefficient between heritage sites is a value derived from the calculation of the average shortest driving time from an industrial heritage site to all other heritage sites. It is defined as the ratio of the average driving time between the industrial heritage site and all other heritage sites to the average driving time between all industrial heritage sites within the study area. The calculation formula is as follows:

$$A_{H,i} = T_{H,i} / \left(\sum_{i=1}^{n} T_{H,i}/n \right) \tag{4}$$

where $A_{H,i}$ is the accessibility coefficient for industrial heritage site i; $T_{H,i}$ is the average shortest driving time from each heritage site to industrial heritage site i; and n is the number of industrial heritage sites within the study area. A smaller value of $A_{H,i}$ indicates better accessibility between the heritage sites. Conversely, a larger value indicates poorer accessibility between the heritage sites.

The accessibility coefficient between heritage sites ranges from 0 to 2, with a mean value of 1. A value greater than 1 indicates that the accessibility between heritage sites for this industrial heritage site is lower than the average accessibility across all industrial heritage sites within the study area. A value less than 1 indicates that the accessibility between the heritage sites is higher than the average accessibility across all industrial heritage sites within the study area [35].

Furthermore, the number of other heritage sites within the driving time threshold is used to represent the richness of surrounding heritage of industrial heritage based on the OD cost matrix of the network analysis method.

3. Results

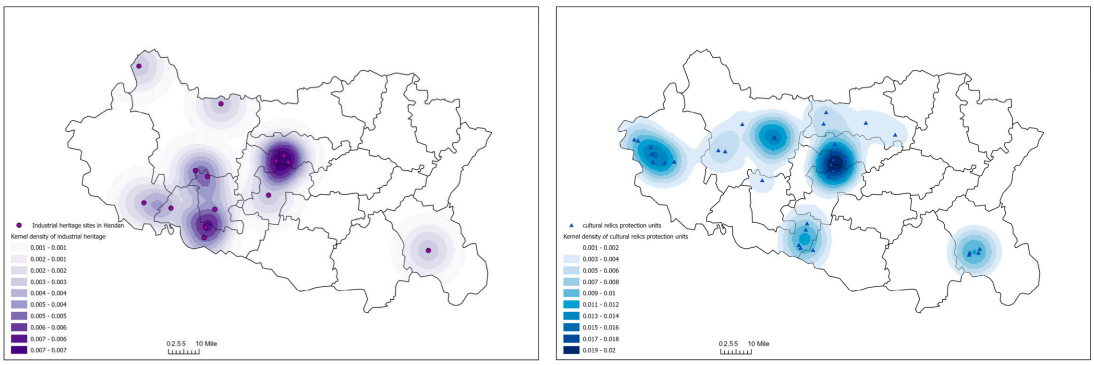
3.1. Analysis of the Spatial Distribution Characteristics of Industrial Heritage Sites in Handan

Using kernel density estimation [36–39], the density distribution of industrial heritage sites and cultural relics protection units in Handan was calculated (Figure 3).

The industrial heritage sites and cultural relics protection units in Handan City exhibit a distinctive spatial distribution pattern characterized by "central overlap and peripheral differentiation." Within the city's core area, these two types of sites are highly concentrated. In the peripheral counties and districts, they tend to cluster separately, driven by different industrial and cultural factors.

The high-density industrial heritage clusters in Handan are primarily concentrated at the junction of the Fuxing District, Hanshan District, and Congtai District, overlapping with the core area of the Zhao culture. The medium-density clusters are mainly located in the Fengfeng Mining District and Ci County, at the terminus of the Fuyang River Cultural Belt. Overall, the industrial heritage sites in western Handan are densely distributed

and numerous, situated within the Taihang Mountain Cultural Belt. In contrast, the industrial heritage sites in the southeastern part of Handan are sparsely distributed and fewer in number, located along the Grand Canal Cultural Belt. The distribution pattern of Handan's industrial heritage is strongly correlated with the distribution of its mineral resources. Handan is rich in mineral resources, and its mining and steel industries are relatively concentrated.



(**a**) (**b**)

Figure 3. (**a**) Kernel density analysis map of Handan industrial heritage sites. (**b**) Kernel density analysis map of cultural heritage conservation units.

The strong spatial correlation between Handan's industrial heritage sites and its cultural relics protection units can be attributed to two factors. First, Handan's urban development is characterized by a strong historical continuity. The ancient sites of the Zhao Royal City and Yecheng City, along with the religious culture of the Xiangtangshan Grottoes and the commercial hub, all fall within regions characterized by high population density, abundant resources, and favorable conditions for industrial development in modern and contemporary times. As a result, these ancient cultural heritage sites and modern industrial heritage sites are spatially concentrated within the same geographic area. Second, the transportation network serving these cultural relics protection units also serves the industrial heritage sites located along the same routes. Likewise, the transportation infrastructure designed for industrial production, logistics, and construction supports the historical attractions along these routes. Regions with high accessibility encompass the majority of Handan's cultural relics protection units, providing a solid geographical and transportation foundation for synergistic development.

3.2. Differences in Overall Accessibility Across Different Transportation Modes

3.2.1. Overall Accessibility Analysis of Handan Industrial Heritage Based on Driving Mode

The network analysis method is employed to assess the overall accessibility of Handan's industrial heritage sites under vehicular travel patterns. The impedance was set as time. Break values were established based on the urban structure and the psychological expectations of the vehicle-using population. Drawing upon relevant literature and the actual conditions in Handan City [40–42], the acceptable travel time intervals for the population were set at 10, 20, 30, 60, and 90 min, as shown in the figure (Figure 4).

We first summarize the service area and its proportion in different time periods for each county and district (Figure 5). Congtai District has the highest proportion of 10-min service zone area at 9.28%. Congtai District, Fuxing District, Hanshan District, and the Fengfeng Mining District all have relatively large short-term service areas, accounting for a high percentage of the county area, exceeding 50%. This high public accessibility enables

the public to more conveniently access cultural services related to industrial heritage, which is beneficial for the popularization and inheritance of cultural memory.

The central urban area is the core of Handan's road network and Zhao culture, with a well-developed network of urban main roads, freeway interchanges, and railway stations, providing good transportation conditions and convenient travel. The industrial heritage in this area mostly consists of large state-owned factories from the "156 Projects" period, such as the Handan Miansan Textile Industrial Heritage Site and certain historic sites of the Hangang Industrial Heritage. These factories were originally built in suburban areas with convenient transportation links. However, as the city expanded, they were gradually encircled by urban development and eventually incorporated into the city center. This area is characterized by high population density, well-developed transportation infrastructure, robust urban facilities, and high demand for urban resident services. As a century-old industrial mining district, the Fengfeng Mining District established comprehensive dedicated railway lines and high-grade highways during the early stages of its development to transport resources such as coal. This infrastructure was utilized not only for industrial logistics but also for passenger transport, ensuring seamless connectivity with the surrounding areas. Industrial heritage is distributed in clusters, with relatively short distances between them, which makes it easy to achieve scale effects.

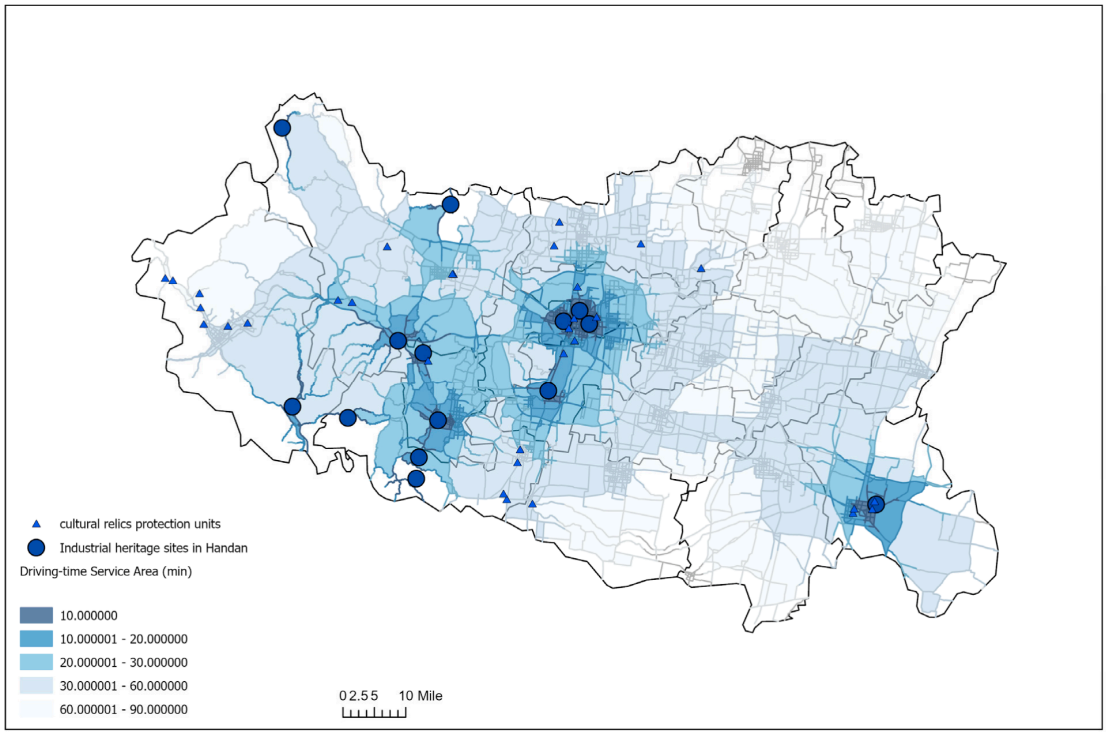
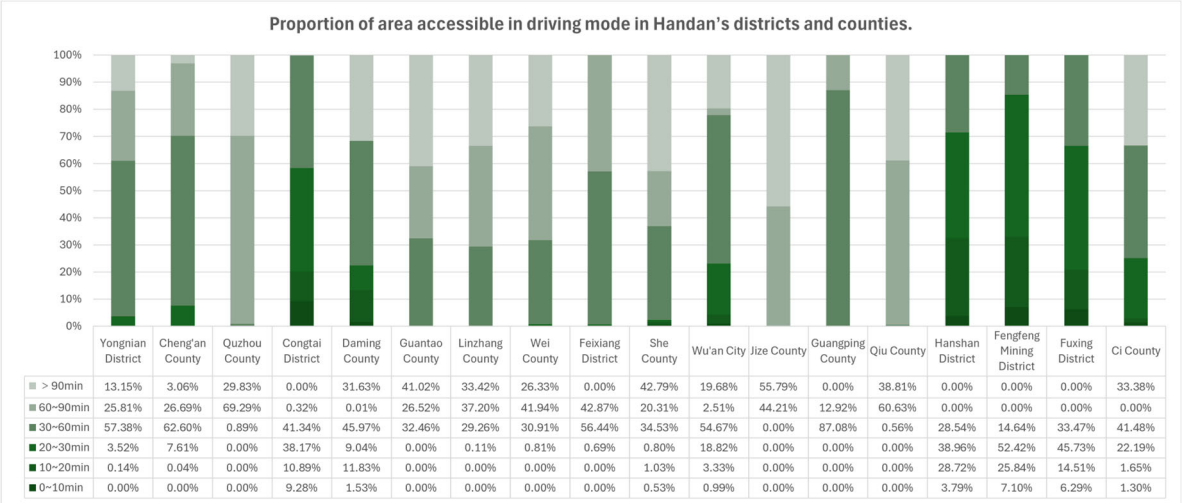


Figure 4. Overall accessibility of Handan's industrial heritage in driving mode.

Areas with a medium proportion of industrial heritage coverage include Daming County, She County, and Wu'an City. The traffic density in the county or district centers is relatively high, but the surrounding areas are not easily accessible, reflecting the imbalance in regional transportation infrastructure. Beyond its transportation infrastructure, the region's cultural resources hold significant appeal for its residents, driving travel activities. Sites such as the Wa Imperial Palace in She County, Jingniang Lake in Wu'an, the red culture sites along the Taihang Mountain Cultural Belt, and the ruins of the Daming Prefecture from the Song Dynasty along the Grand Canal Cultural Belt all possess strong cultural and tourism appeal, effectively stimulating regional visitor flow; industrial heritage

sites typically serve as secondary nodes. The primary purpose of improving regional transportation infrastructure is to serve both tourism and local residents' travel needs, through which industrial heritage sites benefit from an indirect enhancement in accessibility.

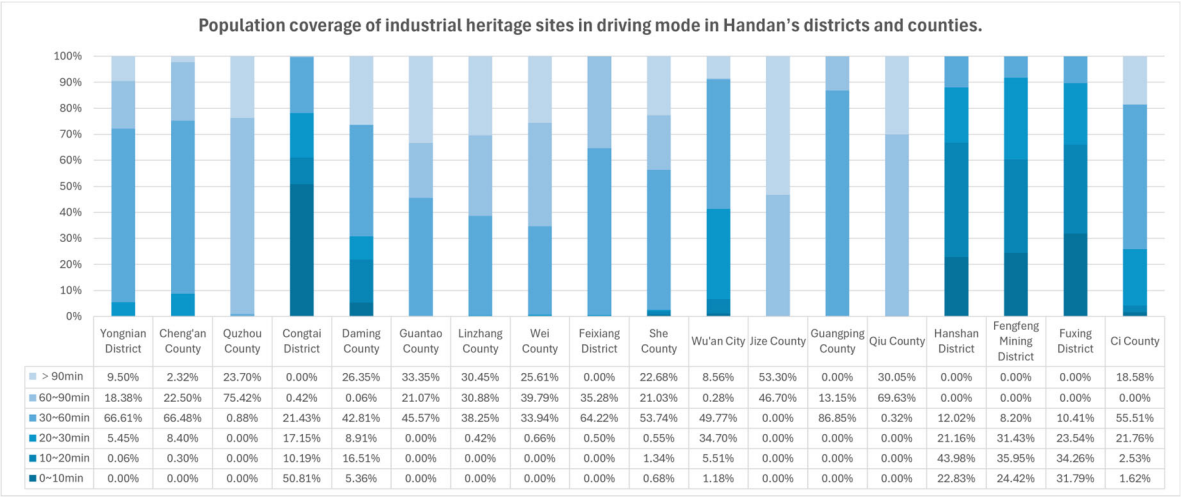


	Yongnian District	Cheng'an County	Quzhou County	Congtai District	Daming County	Guantao County	Linzhang County	Wei County	Feixiang District	She County	Wu'an City	Jize County	Guangping County	Qiu County	Hanshan District	Fengfeng Mining District	Fuxing District	Ci County
> 90min	13.15%	3.06%	29.83%	0.00%	31.63%	41.02%	33.42%	26.33%	0.00%	42.79%	19.68%	55.79%	0.00%	38.81%	0.00%	0.00%	0.00%	33.38%
60~90min	25.81%	26.69%	69.29%	0.32%	0.01%	26.52%	37.20%	41.94%	42.87%	20.31%	2.51%	44.21%	12.92%	60.63%	0.00%	0.00%	0.00%	0.00%
30~60min	57.38%	62.60%	0.89%	41.34%	45.97%	32.46%	29.26%	30.91%	56.44%	34.53%	54.67%	0.00%	87.08%	0.56%	28.54%	14.64%	33.47%	41.48%
20~30min	3.52%	7.61%	0.00%	38.17%	9.04%	0.00%	0.11%	0.81%	0.69%	0.80%	18.82%	0.00%	0.00%	0.00%	38.96%	52.42%	45.73%	22.19%
10~20min	0.14%	0.04%	0.00%	10.89%	11.83%	0.00%	0.00%	0.00%	0.00%	1.03%	3.33%	0.00%	0.00%	0.00%	28.72%	25.84%	14.51%	1.65%
0~10min	0.00%	0.00%	0.00%	9.28%	1.53%	0.00%	0.00%	0.00%	0.00%	0.53%	0.99%	0.00%	0.00%	0.00%	3.79%	7.10%	6.29%	1.30%

Figure 5. Proportion of area accessible in driving mode in Handan's districts and counties.

The remaining areas have a low proportion of accessible land, such as Qiu County, Guantao County, the eastern part of Quzhou County, Jize County, and other eastern counties and districts. These areas are primarily agricultural and lack large industrial and mining heritage sites, with a small number of industrial heritage sites. Located at the end of the regional transportation network, these areas have a low road network density and lack direct connections to high-grade highways or railways, resulting in the highest time cost.

We now calculate the number of people within each district or county who are covered by the service area. Based on the population coverage rate of the service area within each district or county, these districts and counties can be classified into three coverage zones: high, medium, and low (Figure 6).



	Yongnian District	Cheng'an County	Quzhou County	Congtai District	Daming County	Guantao County	Linzhang County	Wei County	Feixiang District	She County	Wu'an City	Jize County	Guangping County	Qiu County	Hanshan District	Fengfeng Mining District	Fuxing District	Ci County
> 90min	9.50%	2.32%	23.70%	0.00%	26.35%	33.35%	30.45%	25.61%	0.00%	22.68%	8.56%	53.30%	0.00%	30.05%	0.00%	0.00%	0.00%	18.58%
60~90min	18.38%	22.50%	75.42%	0.42%	0.06%	21.07%	30.88%	39.79%	35.28%	21.03%	0.28%	46.70%	13.15%	69.63%	0.00%	0.00%	0.00%	0.00%
30~60min	66.61%	66.48%	0.88%	21.43%	42.81%	45.57%	38.25%	33.94%	64.22%	53.74%	49.77%	0.00%	86.85%	0.32%	12.02%	8.20%	10.41%	55.51%
20~30min	5.45%	8.40%	0.00%	17.15%	8.91%	0.00%	0.42%	0.66%	0.50%	0.55%	34.70%	0.00%	0.00%	0.00%	21.16%	31.43%	23.54%	21.76%
10~20min	0.06%	0.30%	0.00%	10.19%	16.51%	0.00%	0.00%	0.00%	0.00%	1.34%	5.51%	0.00%	0.00%	0.00%	43.98%	35.95%	34.26%	2.53%
0~10min	0.00%	0.00%	0.00%	50.81%	5.36%	0.00%	0.00%	0.00%	0.00%	0.68%	1.18%	0.00%	0.00%	0.00%	22.83%	24.42%	31.79%	1.62%

Figure 6. Population coverage of industrial heritage sites in driving mode in Handan's districts and counties.

The high-coverage areas encompass Congtai District, Hanshan District, Fuxing District, and the Fengfeng Mining District. The coverage rates within a 10-min driving time for these four districts are 50.81%, 22.83%, 31.79%, and 24.42%, respectively. The cumulative

coverage rate within a 30-min travel time exceeds 78% in all four districts. This indicates that the majority of residents in the central urban area and the Fengfeng Mining District can reach at least one industrial heritage site within a 30-min driving distance. Notably, the coverage rate within a 10-min driving distance in Congtai District exceeds 50.81%, reflecting the fact that the industrial heritage sites within this district are located in the core of the urban built-up area, surrounded by high population density and an efficient road network. Within a 1-h driving time, these districts and counties have largely achieved comprehensive coverage of industrial heritage services for all their residents.

The medium coverage area encompasses Yongnian District, Cheng'an County, Feixiang District, Guangping County, She County, Wu'an City, Ci County, and Daming County. The 30-min cumulative coverage rate is consistently below 42%, whereas the 60-min cumulative coverage rate exceeds 50% in all these areas. Among these, Yongnian District, Cheng'an County, and Feixiang District are characterized by relatively small district territories with no or very few industrial heritage sites. The residents must reach the industrial heritage through the main roads connecting to the main urban area. The actual travel time is highly dependent on the efficiency of the east-west transportation corridor. As a result, the 30-min cumulative coverage rate remains relatively low, but the 60-min coverage rate increases significantly. The characteristics of She County, Ci County, and Wu'an City in the mountainous area are that the industrial heritage sites are distributed. However, due to the fact that the industrial heritage sites are located in deep mountainous areas or far away from the built-up areas of counties, some areas are blocked by mountains and terrain and the short-term convenient coverage of the population is limited. A large number of residents need a 30–60 min drive to reach an industrial heritage site. As a result, the coverage rate of these industrial heritage sites relative to the total population in these counties and districts is actually lower than in the suburban counties and districts without any such heritage sites. The population coverage rate within the service areas exhibits a gradient increase. Daming County is located on a plain with good road network conditions, but due to its distance from the central urban area, 26.41% of the population still needs more than 60 min to reach industrial heritage sites.

The low-coverage area encompasses Linzhang County, Wei County, Guantao County, Quzhou County, Jize County, and Qiu County. The 30-min cumulative coverage rates for these six counties are all below 10%, and their 60-min cumulative coverage rates are all below 50%. These counties and districts do not host any industrial heritage sites, and they are located relatively far from the central urban industrial heritage cluster. Consequently, it takes residents in these areas more than 60 min to reach any industrial heritage site.

3.2.2. Overall Accessibility Analysis of Handan Industrial Heritage Based on Cycling Modes

The overall accessibility of the industrial heritage in Handan in cycling mode was analyzed using network analysis. The impedance was set as time. Break values were determined based on the urban structure and the psychological expectations of the cycling population. Based on relevant literature and the actual situation of Handan City [43], the acceptable cycling time intervals for the population were set as: 10, 20, 30, 45, and 60 min, as shown in Figure 7.

We summarized the service area sizes and their respective proportions across various counties and districts at different time points (Figure 8). Congtai District, Fuxing District, Hanshan District, and the Fengfeng Mining District have larger areas of service zones accessible by bicycle within short travel distances, accounting for a relatively high percentage of their respective county/district areas. This indicates high convenience for bicycle travel and a significant potential passenger flow. This suggests a plan of thematic bicycle routes that connect multiple heritage sites [44], transforming transportation corridors into immersive

cultural experience corridors. Daming County, Wu'an City, and Ci County are suitable for bicycle tourism within their designated areas. In contrast, bicycle accessibility in other counties is very low, making them unsuitable for slow-paced route connectivity initiatives.

Areas with a high proportion of accessible cycling areas are primarily located in the central urban area, centered around the junction of Congtai District, Fuxing District, and Hanshan District, as well as in the south-central part of Fengfeng Mining District. These areas feature dense road networks and well-developed cycling infrastructure. The 0–20 min cycling radius effectively covers heritage sites in the central urban area, such as the Congtai Liquor Site Museum and the Handan Miansan Textile Industrial Heritage Site, allowing citizens and tourists to reach these heritage sites via green travel. Additionally, it covers the large-scale industrial and mining heritage clusters in the Fengfeng Mining District. Additionally, these regions are areas where cultural relics protection units are relatively concentrated, resulting in a high degree of spatial overlap between industrial heritage sites and cultural relics protection units. This creates favorable conditions for linking cultural resources from different periods and types through bicycle routes, thereby facilitating organized cultural exploration and heritage conservation outreach. The strong non-motorized transport accessibility provides essential transportation support for the adaptive reuse of industrial heritage sites into cultural and creative parks, urban parks [45], and other revitalized spaces.

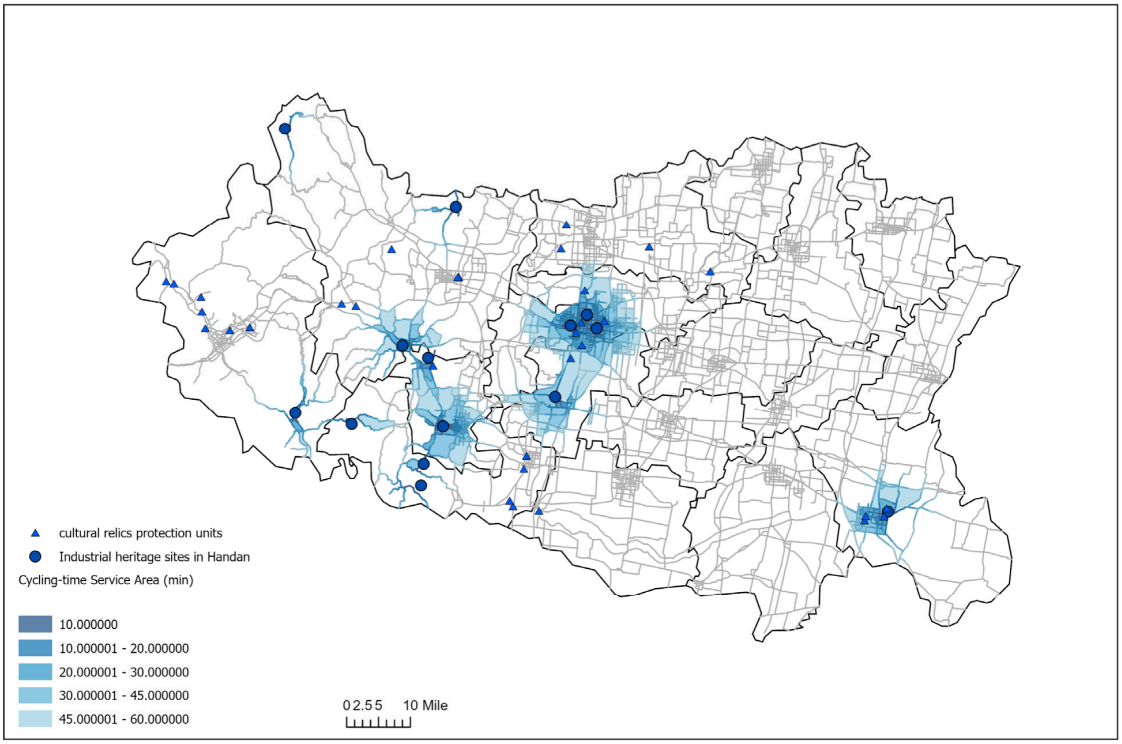
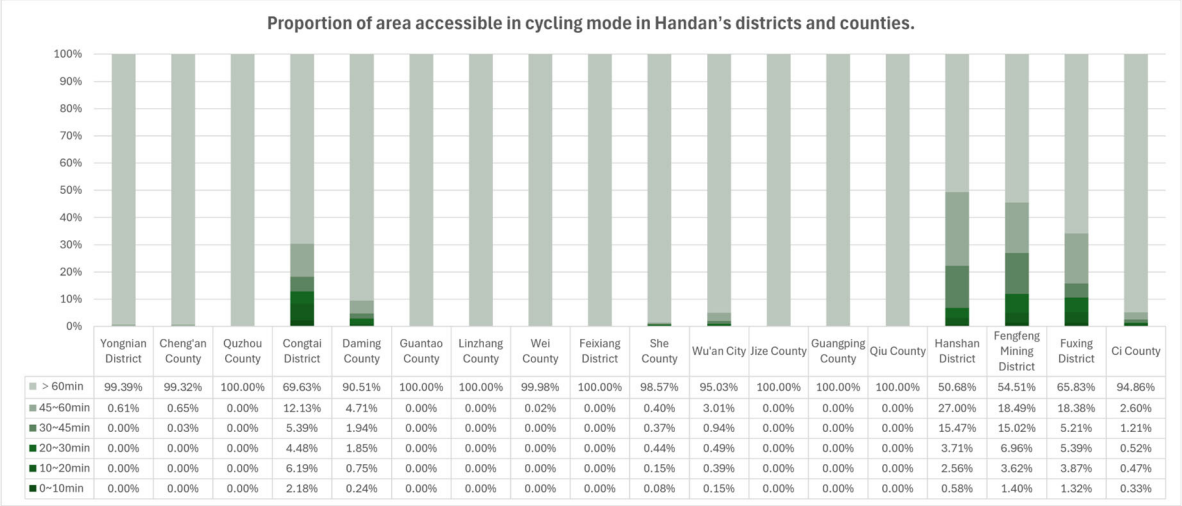


Figure 7. Overall accessibility of Handan industrial heritage sites in the cycling mode.

The areas with a moderate proportion of cycling-accessible service area include the western part of Daming County and the western part of She County. These regions feature an average transportation network density, making it relatively convenient to reach certain industrial heritage sites by bicycle; moreover, the presence of cultural relics protection units in the surrounding areas can facilitate the integration of industrial and historical-cultural resources to some extent. The industrial heritage sites in the western parts of Daming County and She County are not particularly dense, and the historical and cultural attractions are located in areas with low cycling accessibility; although the

travel time cost is higher, these attractions hold significant appeal. Tourist activity in these areas is primarily driven not by industrial heritage sites but by the historical and cultural attractions themselves. The main destinations in this region are the Wa Imperial Palace in She County or the site of the Song Dynasty Daming Prefecture in Daming County, while the surrounding industrial heritage sites represent potential secondary destinations.



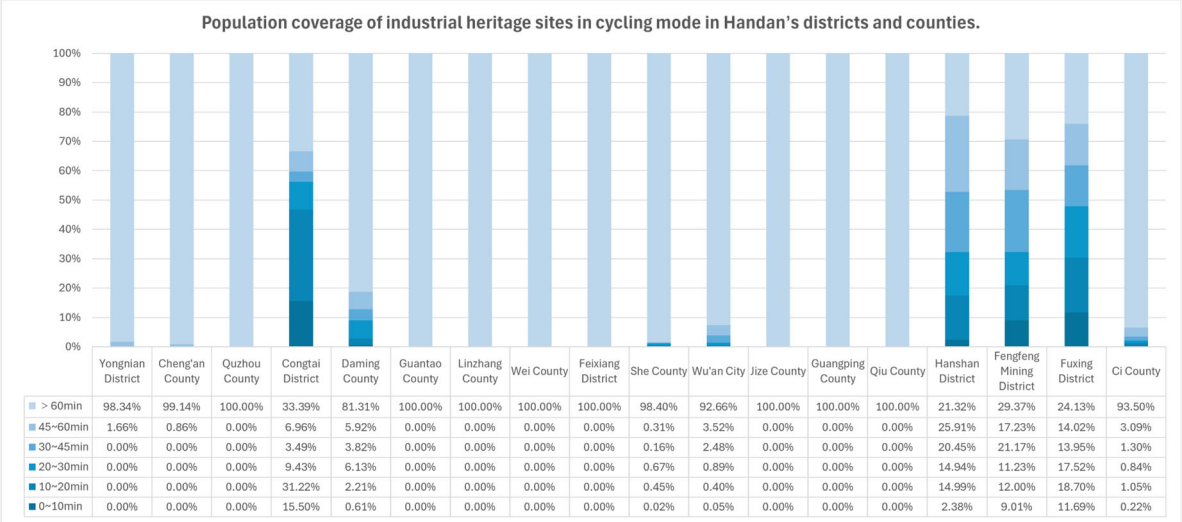
	Yongnian District	Cheng'an County	Quzhou County	Congtai District	Daming County	Guantao County	Linzhang County	Wei County	Feixiang District	She County	Wu'an City	Jize County	Guangping County	Qiu County	Hanshan District	Fengfeng Mining District	Fuxing District	Ci County
> 60min	99.39%	99.32%	100.00%	69.63%	90.51%	100.00%	100.00%	99.98%	100.00%	98.57%	95.03%	100.00%	100.00%	100.00%	50.68%	54.51%	65.83%	94.86%
45~60min	0.61%	0.65%	0.00%	12.13%	4.71%	0.00%	0.00%	0.02%	0.00%	0.40%	3.01%	0.00%	0.00%	0.00%	27.00%	18.49%	18.38%	2.60%
30~45min	0.00%	0.03%	0.00%	5.39%	1.94%	0.00%	0.00%	0.00%	0.00%	0.37%	0.94%	0.00%	0.00%	0.00%	15.47%	15.02%	5.21%	1.21%
20~30min	0.00%	0.00%	0.00%	4.48%	1.85%	0.00%	0.00%	0.00%	0.00%	0.44%	0.49%	0.00%	0.00%	0.00%	3.71%	6.96%	5.39%	0.52%
10~20min	0.00%	0.00%	0.00%	6.19%	0.75%	0.00%	0.00%	0.00%	0.00%	0.15%	0.39%	0.00%	0.00%	0.00%	2.56%	3.62%	3.87%	0.47%
0~10min	0.00%	0.00%	0.00%	2.18%	0.24%	0.00%	0.00%	0.00%	0.00%	0.08%	0.15%	0.00%	0.00%	0.00%	0.58%	1.40%	1.32%	0.33%

Figure 8. Proportion of area accessible in cycling mode in Handan's districts and counties.

The industrial heritage cycling service covers a relatively small area, primarily located in selected parts of Wu'an City and Ci County. Although these areas contain significant industrial heritage sites, the cycling journey is lengthy, the connectivity along main roads is weak, and the industrial heritage sites as well as cultural relics protection units are scattered throughout the region, resulting in considerable time and physical demands. These heritage sites sit at the periphery or at breakpoints of the cycling network, making it difficult for them to integrate effectively into the local cultural landscape, thereby limiting their potential for visitor engagement and revitalization.

Other areas lack a well-planned industrial heritage network, making them unsuitable for cycling.

After calculation, the population coverage rate of industrial heritage service areas in various districts and counties of Handan City in cycling mode was calculated (Figure 9). According to the population coverage rate statistics across these districts and counties, urban accessibility exhibits distinct gradient variations. In Congtai District, Hanshan District, Fuxing District, and the Fengfeng Mining District, the proportion of the population within a 30-min travel distance exceeds 75%, classifying these areas as having high accessibility. The central urban area and the Fengfeng Mining District boast a high density of heritage sites and an extensive road network, providing residents with excellent commuting conditions. For instance, the cumulative 30-min travel coverage rate in Congtai District reaches 46.72%, indicating that the cycling distance between industrial heritage sites in Congtai District and high-density residential areas is relatively short, reflecting the accessibility of community-level cultural facilities. Wu'an City, Ci County, Yongnian District, Cheng'an County, Daming County, and She County have moderate accessibility. Some residents can arrive within half an hour; however, terrain and distance constraints limit the overall coverage extent. In the eastern and southern counties such as Quzhou County, Guantao County, Jizhe County, and Qiu County, the proportion of sites that the population that can reach within 30 min is nearly zero. There is a lack of industrial heritage layout in the region, and the travel cost for residents to access industrial heritage resources is relatively high.



	Yongnian District	Cheng'an County	Quzhou County	Congtai District	Daming County	Guantao County	Linzhang County	Wei County	Feixiang District	She County	Wu'an City	Jize County	Guangping County	Qiu County	Hanshan District	Fengfeng Mining District	Fuxing District	Ci County
> 60min	98.34%	99.14%	100.00%	33.39%	81.31%	100.00%	100.00%	100.00%	100.00%	98.40%	92.66%	100.00%	100.00%	100.00%	21.32%	29.37%	24.13%	93.50%
45~60min	1.66%	0.86%	0.00%	6.96%	5.92%	0.00%	0.00%	0.00%	0.00%	0.31%	3.52%	0.00%	0.00%	0.00%	25.91%	17.23%	14.02%	3.09%
30~45min	0.00%	0.00%	0.00%	3.49%	3.82%	0.00%	0.00%	0.00%	0.00%	0.16%	2.48%	0.00%	0.00%	0.00%	20.45%	21.17%	13.95%	1.30%
20~30min	0.00%	0.00%	0.00%	9.43%	6.13%	0.00%	0.00%	0.00%	0.00%	0.67%	0.89%	0.00%	0.00%	0.00%	14.94%	11.23%	17.52%	0.84%
10~20min	0.00%	0.00%	0.00%	31.22%	2.21%	0.00%	0.00%	0.00%	0.00%	0.45%	0.40%	0.00%	0.00%	0.00%	14.99%	12.00%	18.70%	1.05%
0~10min	0.00%	0.00%	0.00%	15.50%	0.61%	0.00%	0.00%	0.00%	0.00%	0.02%	0.05%	0.00%	0.00%	0.00%	2.38%	9.01%	11.69%	0.22%

Figure 9. Population coverage of industrial heritage sites in cycling mode in Handan's districts and counties.

3.3. Road Network Accessibility of Industrial Heritage

Based on the Handan road traffic network model, the OD cost matrix analysis using the Network Analysis Tool in ArcGIS Pro 3.1.5 was employed to treat driving time as impedance, thereby determining the shortest driving time from the industrial heritage sites to each intersection. The average driving time between the industrial heritage site and each intersection was then calculated to generate a road network accessibility map of the industrial heritage site (Figure 10). From these calculations, the road network accessibility coefficient for the industrial heritage site was derived (Table 2).

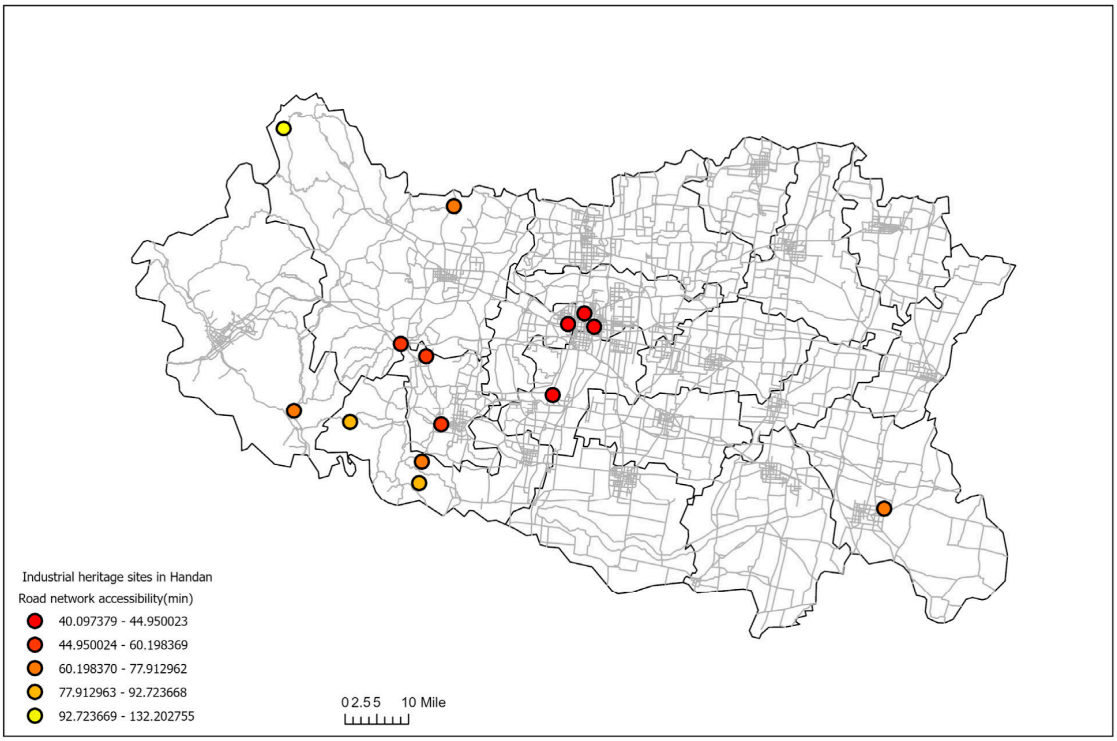


Figure 10. Road network accessibility map of industrial heritage sites in Handan.

Table 2. Road network accessibility coefficients of industrial heritage sites in Handan.

Name	Road Network Accessibility (min)	Road Network Accessibility Coefficient
Handan Miansan Textile Industrial Heritage Site	41.86	0.62
Congtai Liquor Site Museum	40.10	0.60
Former Site of the 129th Division Arsenal of the Eighth Route Army, Huatuo Village, Ci County	92.72	1.38
Hangang Industrial Heritage	41.84	0.62
Former Site of Tong'er Mine	60.20	0.90
Cizhou Kiln Site	60.07	0.89
Ancient Iron Smelting Furnace in Kuangshan Village	67.53	1.01
Xida Ordnance Factory Industrial Heritage Site	77.91	1.16
Cuilu Iron Smelting Site	51.29	0.76
Former Site of Lianggou Arsenal	132.20	1.97
Daming's Centennial Cellar Brewery	70.38	1.05
Shenjiazhuang Coal Mine	72.18	1.07
Former Site of Liuhe Coal Mine	87.13	1.30
Fengfeng Matou Coal Preparation Plant	44.95	0.67

Industrial heritage sites with excellent road network accessibility include the Congtai Liquor Former Site Museum, the Handan Miansan Textile Industrial Heritage Site, Hangang Industrial Heritage, and the Fengfeng Matou Coal Preparation Plant. These sites are all located either within the developed urban area of Handan's main urban center or adjacent to major city thoroughfares. Due to their strategic location at the heart of Handan's historic urban district, these sites have long adhered to the principle of gradual, incremental renewal for the preservation of historic cities. Consequently, no large-scale urban redevelopment or extensive road network alterations have been undertaken, thereby preserving the continuous, dense street network and the spatial fabric of industrial production areas in their original state. The surrounding urban road network features high density and a well-developed road hierarchy. Although the Fengfeng Matou Coal Preparation Plant is situated on the southern edge of the main urban area, it is adjacent to National Highway 107 and the Beijing–Guangzhou Railway Corridor, leveraging this high-grade highway network for excellent external transportation connectivity.

Industrial heritage sites with relatively good road network accessibility include the Cuilu Iron Smelting Site, the Cizhou Kiln Site, and the Former Site of Tong'er Mine. These sites share a common characteristic: they are all located in mining areas or historically significant towns situated on the periphery of Handan's main urban area, with their accessibility falling somewhere between being extremely convenient and being extremely remote. The Former Site of Tong'er Mine and the Cizhou Kiln Site are located within the urban area and its suburbs of the Fengfeng Mining District; they benefit from the road network developed as part of the mining and industrial development in the Fengfeng Mining District, enabling external connectivity. The Cuilu Iron Smelting Site is located in the southern part of Wu'an City, adjacent to a provincial highway, which provides adequate road network access. The accessibility conditions of these heritage sites reflect the public service coverage radius of secondary urban centers. Although they are not situated within the city's core area, the road network coverage in their respective areas is superior to that of rural areas, given that these regions themselves serve urban functions.

Industrial heritage sites with moderate road network accessibility include the Ancient Iron Smelting Furnace in Kuangshan Village, the Daming's Centennial Cellar Brewery, the Shenjiazhuang Coal Mine, and the Xida Ordnance Factory Industrial Heritage Site. There are three primary reasons for the limited accessibility of these sites. First, the Ancient Iron Smelting Furnace in Kuangshan Village, the Shenjiazhuang Coal Mine, and the Xida

Ordnance Factory Industrial Heritage Site are located in the hilly terrain of the eastern foothills of the Taihang Mountains. Consequently, the actual driving distance follows a winding route along the topography, which is significantly longer than the straight-line distance. Although the Daming's Centennial Cellar Brewery is situated in a flat area, it lies at the eastern terminus of Handan City's road network, where the road class deteriorates rapidly when extending eastward. Second, these sites are located far from the main urban area of Handan. The roads connecting them are predominantly county or township roads, which feature low road classes and low design speeds. Third, there is no direct high-grade highway connection between these heritage sites and the main urban area of Handan. Thus, access to the regional arterial road network requires multiple transitions between different road network tiers. Each such transition incurs additional time costs, and the cumulative effect results in a significant increase in the total driving time.

The road network accessibility to industrial heritage sites is limited, encompassing the Former Site of Liuhe Coal Mine and the former site of the 129th Division Arsenal of the Eighth Route Army in Huatuo Village, Ci County. Both sites are located within the Dongtaihang Mountain Range in the western part of Handan City. The terrain dictates that the road network can only be laid out along river valleys or along a few limited ridge corridors, making it impossible to establish a networked connectivity structure.

The site with the lowest road network accessibility for industrial heritage is the Former Site of Lianggou Arsenal, located in the heart of the Taihang Mountains in the northwestern part of Wu'an City. Most access roads are winding mountain roads; due to the challenging terrain, the road network density is extremely low and the road curvature is high, resulting in driving times that exceed conventional expectations.

3.4. Accessibility Between Heritage Sites

Based on the Handan road traffic network model, the OD cost matrix analysis using the Network Analysis Tool in ArcGIS Pro was employed to treat driving time as impedance, thereby determining the shortest driving time from one industrial heritage site to each other heritage site. The average driving time between the industrial heritage sites was then calculated to generate the inter-heritage accessibility map (Figure 11). Then, the corresponding accessibility coefficient between sites of industrial heritage was derived (Table 3).

Table 3. Accessibility coefficient between sites of Handan industrial heritage.

Name	Accessibility Between Heritage Sites (min)	Accessibility Coefficient Between Heritage Sites
Handan Miansan Textile Industrial Heritage Site	45.69	0.72
Congtai Liquor Site Museum	45.40	0.72
Former Site of the 129th Division Arsenal of the Eighth Route Army, Huatuo Village, Ci County	78.85	1.25
Hangang Industrial Heritage	43.40	0.69
Former Site of Tong'er Mine	50.59	0.80
Cizhou Kiln Site	54.71	0.87
Ancient Iron Smelting Furnace in Kuangshan Village	60.12	0.95
Xida Ordnance Factory Industrial Heritage Site	63.59	1.01
Cuilu Iron Smelting Site	42.12	0.67
Former Site of Lianggou Arsenal	119.13	1.88
Daming's Centennial Cellar Brewery	89.18	1.41
Shenjiazhuang Coal Mine	65.22	1.03
Former Site of Liuhe Coal Mine	79.83	1.26
Fengfeng Matou Coal Preparation Plant	47.37	0.75

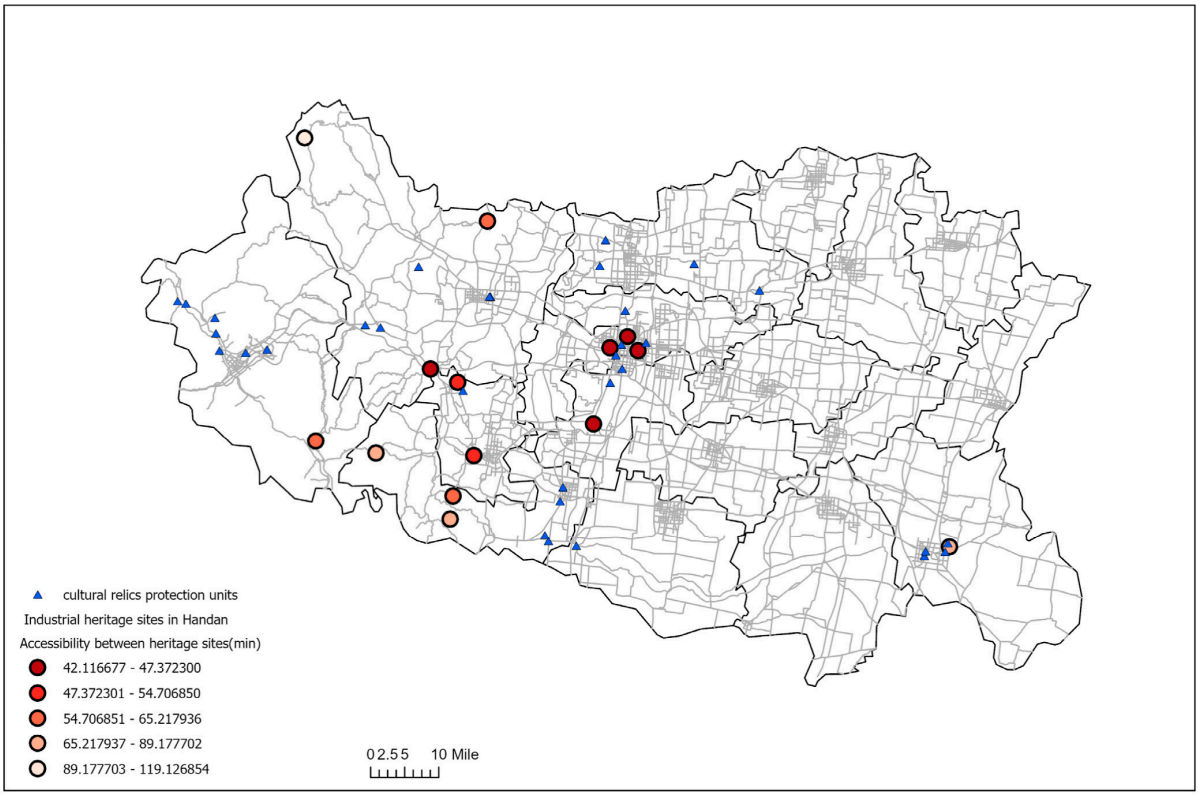


Figure 11. Accessibility between sites of Handan industrial heritage.

Eight industrial heritage sites exhibited accessibility coefficients between heritage sites of below 1, indicating that the accessibility among these sites exceeds the average value. Industrial heritage sites with high accessibility between heritage sites are distributed in the central urban area and the western region. The accessibility between the sites of industrial heritage in the eastern part of the city is poor. Industrial heritage sites with high accessibility between heritage sites exhibit relatively large differences between themselves. The reason for this characteristic is that the central urban area and the western part of Handan have the densest concentrations of industrial heritage and cultural protection sites, along with well-developed road networks, while the eastern area has more road networks but fewer industrial heritage and cultural protection sites.

The high accessibility between heritage sites in the central urban area is not only due to the dense distribution of industrial heritage sites, but also to the large number and concentrated distribution of cultural relics protection units. When developing such clusters, consideration should be given to the transition and integration of different heritage styles. The high accessibility between heritage sites in the western region is attributed to the relatively large number and concentrated distribution of industrial heritage sites, along with a small number of cultural relics protection units in the surrounding area. For cluster development, it is advisable to create industrial heritage-themed tour routes [46].

The number of other industrial heritage sites and cultural heritage protection units reachable within each driving time threshold was calculated and compiled. The surrounding heritage richness is reflected by the number of other industrial heritage sites and cultural relics protection units accessible within each time-period travel range (Figure 12). Seven of these industrial heritage sites can be reached from other industrial heritage sites or cultural relics protection units within 10 min. This indicates that half of the industrial heritage sites are mutually accessible to one another within a relatively short driving time.



Figure 12. Number of reachable heritage sites within each driving time threshold from industrial heritage sites in Handan.

Among them, the Handan Miansan Textile Industrial Heritage Site and Congtai Liquor Site Museum located in the city center have the highest number of other industrial heritage sites and cultural heritage sites that can be reached within a 10-min, 20-min, and 30-min travel circle. The concentration of industrial heritage is the highest there, and there are more choices to go to other heritage sites. The Cuilu Iron Smelting Site and the Fengfeng Matou Coal Preparation Plant, which are both within a 30-min travel circle, have more than ten other industrial heritage sites and cultural relics protection units nearby, indicating favorable surrounding heritage richness. However, the number of such sites accessible within 10-min or 20-min travel circles is relatively small. Daming's Centennial Cellar Brewery has only four other industrial heritage sites and cultural relics protection units within its 10-min, 20-min, and 30-min travel circles. It shows relatively good surrounding heritage richness in the 10-min isochrone, whereas its surrounding heritage richness is moderate within the 30-min driving time isochrone. This phenomenon is attributable to the fact that while there are fewer eastern industrial heritage sites and cultural relics protection units, those that do exist are concentrated within Daming County. Industrial heritage sites including the Shenjiazhuang Coal Mine, the Former Site of Liuhe Coal Mine, and the Former Site of Lianggou Arsenal have few or no other reachable industrial heritage sites and cultural relic protection units within the 30-min driving time isochrone.

For the remaining industrial heritage sites, the number of other industrial heritage sites and cultural relics protection units within a 30-min travel circle ranges from 4 to 7, representing a moderate level of surrounding heritage richness.

4. Discussion

4.1. The Formation Mechanisms Underlying the Overall Accessibility Pattern

The overall accessibility pattern of industrial heritage in Handan City exhibits a distinct hierarchical gradient differentiation feature. It forms a spatial structure where the central urban area and the Fengfeng Mining District have high coverage, the central plains and mountainous counties have medium coverage, and the southeastern counties have low coverage. This pattern is not the result of a single road network factor, but rather the outcome of a combination of factors, including the historical spatial layout, population distribution, topography, and geographical distances.

The high-coverage areas are concentrated in the central urban districts (Congtai District, Hanshan District, Fuxing District) and the Fengfeng Mining District. The industrial heritage in the urban center is embedded in the core of the built-up area of the city. The

industrial heritage has nearby service capability for urban-level public cultural services. The Fengfeng Mining District, relying on the cluster of industrial and mining relics and the mature industrial supporting road system, forms an independently highly accessible area within the city. Within 30 min of driving, most residents in the jurisdiction can be covered, and the entire area can be covered within one hour.

The medium-coverage areas and counties exhibit two distinct mechanisms. In plain-area counties such as Yongnian District, Cheng'an County, and Feixiang District, which are located near the main urban center, there is a scarcity of local industrial heritage sites. As a result, residents rely on major external roads to access the heritage resources within the central urban area. Therefore, coverage within the 30-min range is limited, while coverage within the 60-min range increases rapidly; accessibility depends heavily on the efficiency of intercity connectivity. In contrast, although Wu'an City, She County, and Ci County contain industrial heritage sites, these sites are predominantly situated in mountainous or hilly regions, far removed from urban built-up areas. The topographic barriers diminish their short-term population accessibility capacity, leading to an overall coverage level that is actually lower than that of the suburban plain-area counties without any industrial heritage.

The southeastern counties such as Linzhang County, Wei County, Guantao County, Quzhou County, Jize County, and Qiu County belong to the areas with overall low coverage. There are no local industrial heritage sites and the distance to the two major industrial heritage clusters is too far, which are the fundamental causes. For both driving and cycling modes, the short-term population coverage rate is extremely low, and the travel cost for residents to access industrial heritage resources is significantly high.

The integrated dual-mode analysis reveals that the spatial alignment between industrial heritage concentration and population distribution is the core factor determining the accessibility foundation. The topographic conditions regulate the service efficiency of mountainous heritage, and the distance between locations determines the overall coverage gradient of the county. These factors collectively shape the differentiated public service accessibility pattern for industrial heritage sites in Handan City.

4.2. Accessibility of Industrial Heritage Under the Constraints of Historical and Cultural City Protection

Due to limitations imposed by the restricted public availability of planning data, this study adopts a research approach that combines quantitative potential assessment with qualitative overlay-based management rules.

The road network accessibility analysis reveals that the central urban area boasts the most favorable conditions for industrial heritage road network accessibility. The Congtai Liquor Site Museum, Handan Miansan Textile Industrial Heritage Site, and Hangang Industrial Heritage are all integrated into the historic urban area. Thanks to Handan's gradual, micro-level renewal strategy for its historic district, the fabric of the old city's streets and alleys and its industrial spatial layout have not been subject to large-scale demolition or redevelopment. Instead, a dense, continuous road network has been preserved and augmented with a high-density urban arterial road system, creating excellent vehicular traffic conditions.

The accessibility between heritage sites further reveals the varying degrees of integration of industrial heritage within the overall cultural system of the historic city. The superior accessibility of industrial heritage sites in the central urban area stems not only from the density of its road network but also from the high concentration of cultural relics protection units within the old city, as well as the nested distribution of industrial heritage sites alongside historical and cultural resources, which creates a network foundation conducive to the interconnection of ancient and modern heritage sites. In the western areas, including

the Fengfeng Mining District and Wu'an City, the high accessibility between heritage sites is primarily attributable to the clustered distribution of industrial heritage sites themselves, giving rise to a thematic resource cluster centered on industrial heritage. This cluster is adjacent to the Yecheng and Xiangtang cultural resource clusters. Although less subject to the constraints imposed by the urban landscape management regulations of the renowned city, these two types of resources complement each other spatially and possess the potential to mutually attract visitors. In the eastern counties of the municipality, the road network is relatively well-organized, yet the distribution of cultural heritage sites across the entire area is sparse, resulting in the weakest connectivity for industrial heritage sites.

The comprehensive accessibility analysis reveals a clear spatial disparity. Urban areas boast robust road networks and strong cultural connectivity, the western region suffers from inadequate road infrastructure but exhibits strong industrial cluster integration, and the eastern region has moderate road connectivity but the weakest cultural connectivity. Under the constraints of historic and cultural city conservation, the potential for vehicular accessibility alone cannot be directly equated with development value. Highlyaccessible heritage sites in the central urban area should be aligned with the regulatory framework governing the old town's character, minimizing motor vehicle development and promoting the integration of non-motorized transport. Industrial and mining clusters can leverage their existing transportation infrastructure to develop industrial-themed tourism routes. Mountainous areas with low-accessibility heritage, constrained by both topography and urban character, are best suited for point-based conservation and the preservation of the site's original fabric. This dual-layered indicator system effectively distinguishes between transportation accessibility potential and the compatibility with the historic city's cultural framework, better aligning with the principle of collaborative, multi-tiered heritage conservation in historic cities.

Compared with existing research on the accessibility of industrial heritage, this article focuses not only on the accessibility of the road network but also analyzes the accessibility between heritage sites and discusses accessibility differences in combination with the protection framework of historical and cultural cities. Previous studies have emphasized and focused on the external accessibility conditions of a certain type of heritage. This article further finds that the accessibility of industrial heritage in historical and cultural cities is also influenced by industrial layout and the conservation framework of historical and cultural cities, providing a supplementary perspective for the renewal of industrial heritage and the continuation of cultural context in urban historical and cultural spaces.

4.3. Limitations and Future Prospects

Due to limitations imposed by publicly available spatial data, this study was unable to incorporate traffic control measures for the historic urban area and its historic streets and alleys into the quantitative model; this represents a primary limitation of the present research. Within the "One City, One Street; Two Axes, Ten Alleys" spatial pattern of Handan's historic urban area, the core section of the Chuangcheng Street Historical and Cultural District imposes restrictions on motor vehicle traffic. Therefore, even when the accessibility coefficient for certain heritage areas is relatively high, the large-scale introduction of motorized tourist transportation is not advisable. Future research, should it obtain official protection zone vector data, could further refine the model's constraint conditions.

Due to the limitations of the official and website data release cycle and update frequency, some road, population data, and heritage information may have time lag and attribute accuracy differences. The spatial resolution of population raster data may also affect the population coverage calculation results. This further affects the accuracy of accessibility analysis. Due to limitations in the selection criteria for industrial heritage,

some industrial remains that are relatively new in age have not yet completed value recognition, lack systematic records may be overlooked, which may have a certain impact on the spatial distribution pattern and accessibility evaluation. Future research can continue to investigate, supplement, and improve based on official data updates.

When setting impedance, the driving mode adopts fixed speed parameters based on road grades, and the bicycle riding mode uses a unified speed of 15 km/h to construct an analysis framework. It reflects the accessibility potential under baseline conditions, but cannot capture the dynamic fluctuations of traffic flows during different time periods such as workdays and holidays. At the same time, actual traffic operations are affected by factors such as congestion, road infrastructure conditions, intersection delays, slope, and temporal variations, which may result in differences between actual travel times and model estimates. Future research could introduce higher-resolution population data and conduct sensitivity analyses based on multi-period traffic data and different speed parameter settings to further verify the impact of different impedance settings on evaluation results, and improve the refinement level of analysis results.

The protection and renewal of industrial heritage is a complex issue involving society, culture, economy, and environment. Future research could further integrate multidimensional factors such as heritage value, preservation status, social needs, economic feasibility, and environmental impact based on accessibility evaluation and adopt interdisciplinary methods such as sociology, economics, and environmental science to provide a more comprehensive decision-making basis for the protection, renewal, and dynamic regeneration of industrial heritage.

4.4. Insights from the Conservation and Renewal of Industrial Heritage

Based on the multi-level accessibility evaluation results of existing spatial data, combined with the historical and cultural protection pattern of "one core, two cities, and three belts" in Handan, this article proposes a conservation and regeneration approach that integrates zonal targeted strategies, priority to heritage fabric conservation, and phased implementation according to the spatial distribution characteristics and accessibility differences of industrial heritage.

For highly accessible heritage sites located in the central urban area, the connection between industrial heritage, surrounding historical and cultural resources, and public spaces should be strengthened, and protection and control should be carried out in conjunction with the historical urban texture. New plans should emphasize the organic integration with the city's slow-traffic system and the character of the old town. The update should prioritize slow traffic instead of a motor vehicle orientation, avoiding excessive motorized development through slow traffic such as walking and cycling. Low motor vehicle permeability can be transformed into cultural experience resources, which aligns with the goal of optimizing the pedestrian system in the historical district of the city protection plan of Handan City. When renovating industrial heritage sites such as the Congtai Liquor Site Museum and the Handan Miansan Textile Industrial Heritage Site located in the historic city area, it is necessary to optimize urban public space and landscape design, strengthen the physical and visual connections between industrial heritage and surrounding historical and cultural areas, and reduce the barriers between industrial heritage and the historic urban character. Through street and alley interface improvement and heritage living room style buffer space design, buffer reception and exhibition composite spaces should be set up outside the core protection area. At the same time, the principle of minimal intervention should be followed to avoid large-scale demolition and construction. Planners should adopt micro renewal methods, retain the structural framework and facade features of industrial buildings, and carry out light intervention renovations internally [47], so as to

protect the historical character and original structural features of industrial heritage. The renewal strategy should not be solely geared toward tourists but should also facilitate integration into the city's everyday cultural life, with a focus on functional activation and route organization. According to the characteristics of industrial heritage and surrounding demands, appropriate targeted functions and diverse governance should be introduced. The plan should be to gradually shift industrial heritage from a single display space to a cultural space that integrates into daily urban life. Micro-regeneration approaches that embed heritage into routine urban cultural life can be explored to achieve coordination between conservation and adaptive reuse.

For industrial and mining clusters, existing transportation infrastructure can be relied upon, or abandoned industrial transportation facilities such as disused railway lines can be utilized to create industrial themed tourism routes, strengthen node linkage, and achieve the organic combination of industrial heritage with historical and cultural relics.

For low accessibility areas such as mountains, transportation and infrastructure improvement conditions are limited. Considering the value of industrial heritage, small-scale and gradual micro updates and traffic organization optimization measures can be prioritized, and the update scope can be gradually adjusted according to the implementation effect and actual needs to reduce the implementation risks brought by large-scale construction. The approach should focus on point-based conservation and the preservation of the site's original fabric, with cautious consideration given to large-scale development projects, thereby achieving a precise alignment between transportation potential and cultural value and facilitating the synergistic conservation and sustainable utilization of industrial heritage across the entire area [48]. For example, the Former Site of Lianggou Arsenal has been incorporated into the collaborative development framework for the Great Wall National Cultural Park. It is located at the end of the road network and has high short-term transportation improvement costs and low benefits. Therefore, it should focus on the protection of the site and value interpretation, and implement graded protection. It is not suitable to directly carry out large-scale public construction and infrastructure renovation.

For low accessibility areas with insufficient transportation connections but conditions for improvement, it is proposed to optimize transportation connections and enhance regional accessibility. In addition, the premise of fully identifying a site's historical and cultural value and protection requirements, necessary transportation connections, heritage site exhibitions, and spatial utilization measures should be considered, rather than solely determining protection methods or development intensity based on its accessibility level. For example, external transport connections in the eastern area can be optimized. Meanwhile, in line with the slow-traffic management requirements for the historic urban area of Daming County, non-motorized vehicle interchange points shall be established at key industrial heritage sites along the urban periphery to create a shared bicycle transfer system, thereby guiding tourists to adopt slow-traffic modes of transport when accessing the historical and cultural precincts of Daming Ancient City while balancing industrial heritage tourism with the preservation of the ancient city's traditional character.

The above differentiated conservation and regeneration strategies are mainly based on accessibility analysis. At the stage of practical project implementation, it is necessary to combine multiple dimensions such as heritage value assessment, building preservation status, property rights coordination, economic feasibility, and tourist demand to form the final implementation plan. In specific updating practices, communication and collaboration with local residents, relevant experts, enterprises, and policy management departments should be strengthened to address the limitations of the spatial data in this article. Local practical demands and conservation management requirements should be fully considered to achieve alignment with regional sustainable development goals. Through

phased evaluation, continuous monitoring, and feedback, regeneration measures can be dynamically adjusted.

This study offers a new research perspective for the conservation and regeneration of industrial heritage within the overall conservation system of historic and cultural cities and provides references for promoting coordinated regional development. It provides spatial evidence for the integration, coordination, and sustainable conservation of industrial heritage and historic and cultural resources. The accessibility analysis and differentiated regeneration strategies in the context of historic and cultural cities offer references for the urban transformation of cities with the dual identity of historic and cultural cities and industrial cities.

5. Conclusions

This study starts from the continuity of the survival of historical and cultural cities and uses kernel density analysis and network analysis to analyze the distribution characteristics of industrial heritage in Handan. It also analyzes overall accessibility for different types of transportation, road network accessibility, and accessibility between sites of industrial heritage. Combined with the distribution of historical and cultural resources, it explores strategies for the conservation and dynamic regeneration of industrial heritage. The study revealed the accessibility characteristics of industrial heritage in Handan and its correlation with historical and cultural resources, providing a spatial analysis basis for the integration of industrial heritage into the protection of historical and cultural cities. From the above analysis, the following conclusions can be drawn:

1. The overall accessibility of industrial heritage in Handan City presents a hierarchical pattern of high coverage in the central urban area and the Fengfeng Mining District, medium coverage in the central area, and low coverage in the eastern area. The reason for this is the comprehensive effect of multiple factors such as heritage spatial layout, population agglomeration distribution, topography, and location distance.
2. An analysis of the service area coverage and population coverage rate of integrated driving and cycling mode services reveals a significant gradient variation in the accessibility of industrial heritage sites in Handan City: Congtai District, Hanshan District, Fuxing District, and the Fengfeng Mining District all exhibit the highest levels of overall accessibility for both travel options, providing ideal conditions for organizing immersive slow-paced tourism routes for industrial heritage sites. In Daming County, Wu'an City, and Ci County, road travel accessibility is superior to cycling. For the remaining counties in the eastern and southern regions, the coverage for both modes of travel is extremely low. Thus, priority should be given to improving their external transport linkages.
3. A spatial mismatch exists between road network accessibility and the accessibility between heritage sites. The central urban heritage sites are seamlessly integrated into both a high-density road network and a dense network of cultural heritage sites, creating a dual synergistic advantage. The Fengfeng Industrial and Mining Area exhibits a distinctive single-industrial cluster pattern characterized by "high road network accessibility and moderate cultural embedding". The western mountainous regions face a structural constraint characterized by high cultural embeddedness and low accessibility, stemming from a combination of "resource concentration and underdeveloped road networks." The eastern region generally faces the challenge of limited road network infrastructure and a dual scarcity of heritage resources.
4. The central urban area exhibits the highest richness of surrounding heritage resources and has a solid foundation for resource integration. The industrial heritage in the

western region is relatively highly concentrated within a 30-min travel radius, with potential to create themed sightseeing loops.

The research results provide new research perspectives and empirical support for the dynamic regeneration of industrial heritage, coordinated regional development, and industrial urban transformation within the framework of historic and cultural cities. Based on the analysis results, this article proposes a differentiated conservation and planning strategy that combines zoning guidance, priority for heritage site physical integrity conservation, slow driving encouragement, and phased implementation. The industrial heritage in the central urban area should strengthen the integration of slow traffic and the linkage of cultural heritage resources. Industrial and mining clusters can rely on transportation infrastructure to organize industrial themed routes. Low accessibility industrial heritage in mountainous areas should focus on the protection of the original structure and preservation of the texture and strictly control large-scale development. Priority should be given to filling the gaps in transportation infrastructure in the eastern edge counties, gradually improving the public service coverage capacity of industrial heritage resources. Future research can combine dynamic traffic data and interdisciplinary research methods to further improve the comprehensive accessibility evaluation system of industrial heritage from the perspective of historical and cultural cities, providing more comprehensive support for the dynamic regeneration and sustainable conservation of industrial heritage.

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