Evaluation Method of Composite Development Bus Terminal Using Multi-Source Data Processing

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Abstract: Given the accelerating speed and scale of urbanization in China, a rational formulation of a composite development plan to increase the vitality and value of various areas is required. Thus, this study proposes a method for evaluating the spatial relationship among facilities around bus terminals by combining urban points-of-interest data and street view image data from two perspectives: the current level of development and potential of the terminals, and an evaluation of the surrounding pedestrian environment. This is in response to the lack of quantitative descriptions of the composite development of existing bus terminals. The validity and applicability of the methods are verified using the samples of five planned composite development bus terminals in the city of Zhengzhou. These results offer strategic suggestions for the composite development of the Zhengzhou bus terminals. This study demonstrates innovation in integrating geographic information data and street view images. It reflects the spatial characteristics of the built environment using geographic information data and the visual characteristics of the built environment using street view images.

Keywords: bus terminal; composite development; built environment; spatial relationship; machine learning; semantic segmentation

1. Introduction

With the accelerating speed and scale of urbanization in China, the increasing numbers of motor vehicles, wastage of land resources, and environmental pollution have become serious problems and major obstacles to sustainable urban development. Many cities have responded to this problem by implementing traffic control measures such as vehicle restrictions and congestion pricing. Based on practical experience from some cities, the vehicle restriction policy can indeed reduce people’s tendency to choose motor vehicle travel in the short term, but the continued rapid growth of the number of motor vehicles leads to a gradual weakening of this measure, especially in the long run [1–3]. Furthermore, the implementation of a congestion pricing policy can cause disputes in social fairness. In practice, targeted control measures for urban traffic problems can only temporarily alleviate congestion, whereas the long-term contradiction of a mismatch between supply and demand of traffic trips remains difficult to solve. Therefore, many scholars advocate the model of “transit-oriented development (TOD)”, hoping to improve the urban environment through a combination of land-use and transportation planning, expecting to promote the integrated development of transportation and land, and fundamentally solving the problem of the gap between the supply and demand of transportation and travel [4–6].

TOD is widely regarded as an effective way to integrate transportation and land use. Its primary significance lies in the high-intensity and multi-functional development around public transportation stations, complemented by the design of a pleasant pedestrian environment to reduce people’s dependence on private motor vehicles [5]. Since the 1990s, research on TOD has become a topic of interest for governments and research institutions [7].
Considerable empirical evidence suggests that TOD not only increases the frequency of walking and transit trips but also significantly reduces the willingness of people to choose motorized trips. For example, Nasri and Zhang (2014) found that TOD areas in Washington and Baltimore in the United States had approximately 38% and 21% lower motor vehicle miles traveled, respectively, compared with non-TOD areas [8]. Tian et al.’s (2017) survey found 1.7 times more walking trips around Seattle TOD areas than in non-TOD areas, and motor vehicle miles and parking demand were significantly lower than previously recorded [9]. Most existing studies on TOD development models focus on rail transit stations [5,10,11]. However, the high construction costs of rail transit systems are not suitable for all cities. Hence, it is necessary to consider all possible means for urban public transport [12].

The city bus network and the bus terminal are the core of a bus network and constitute critical infrastructure in the entire bus system. China’s current government-led bus terminal construction and operation model often stands in contrast to the surrounding land and facilities, resulting in a disconnect between the bus terminal and the development of the surrounding land and facilities, preventing the former from playing a central role as a hub [13]. As an emerging model for solving such problems, the compound development of bus terminals has been widely supported by relevant national and local policy documents. Some cities’ bus groups and real estate developers have also begun to explore this mode of construction and operation by introducing a mix of multiple businesses, improving the road environment, and optimizing bus routes and stations, among other measures, to enhance the bus terminal’s attractiveness for passengers, increasing passenger flow, and thereby the area’s commercial value [14]. Therefore, objectively measuring the spatial relationship of the facilities around the bus terminal from the perspective of public transportation is a basic prerequisite for the rational formulation of a composite development plan and for increasing the vitality and value of the area. Simultaneously, the bus terminal, the organizational core of the city’s public transport system, should be fully considered in terms of the interrelationship between public transport and facilities within its radius. This will provide the appropriate mechanism and planning basis for promoting public transport development and improving land utilization.

Hence, combined with existing research, this study uses spatial syntax, network analysis, and machine-learning semantic segmentation to investigate the spatial relationship between bus terminals and surrounding facilities from two perspectives: the development level and potential, and the pedestrian environment. Specifically, this study aims to:
(1) construct descriptive indexes of the spatial relationship of the facilities around the bus terminal from the perspective of public transportation; (2) verify the rationality of the composite development plan of the bus terminal; and (3) propose an optimization strategy for the composite development of the bus terminal and an improvement strategy for pedestrian environment.

The remainder of this paper is organized as follows. Section 2 reviews the literature. Section 3 explains the method and data. Section 4 provides the case analysis. Finally, Section 5 concludes the study and presents its contributions to the literature.

1.1. Bus Terminal Optimization Strategies

Numerous scholars have extensively discussed the land resource allocation scheme for developing bus terminal complexes. He and Yang (2019) believed that to solve the shortage of land for bus terminals, cut down on operating losses, and address other problems proposed in the application of the land planning of bus terminals, the ideas of both the land planning department and bus operating company should be considered [15]. This includes applying for more land for bus terminal development in the remote areas of the city and initiating new routes for the newly developed bus station. Given the current situation of limited land for bus terminals in Shenzhen, Lin et al. (2013) proposed an implementation mechanism for the transformation and upgrading of the secondary development of bus terminal land in the future, drawing on the experience of the comprehensive development
of bus terminals in Hong Kong. In contrast, the study of bus terminal optimization is mainly from the perspective of the transportation network, which is through the optimization of routes, station locations, and other measures to increase their utilization efficiency, thereby improving operational efficiency [16]. For example, Mahadikar et al. (2015) optimized the bus routes operated by the Bangalore Metropolitan Transport Corporation to reduce the number of empty miles [17]. Nasibov et al. (2013) proposed four optimization models for different types of bus routes in Izmir to reduce empty miles [18]. Chen et al. (2021) developed a queuing-siting-assignment model that optimizes the bus garage system and planning entry and exit routes to and from the garage for different buses, thereby reducing operating costs [19].

The existing research on bus terminals reveals that the composite development strategy of bus terminals and the optimization of bus routes have achieved certain results. In particular, more sophisticated research has been conducted on the optimization of bus routes and stations [17,20,21] using topological and spatial analyses and nonlinear programming models. The bus terminal, as the organizational core of the bus network, connects the surrounding areas and facilities via the road system, bus line network, and bus station, serving as the central driver of transportation. However, existing studies continue to focus on the traffic properties of the bus terminal itself, with insufficient attention paid to the spatial relationship between the facilities around the bus terminal. This is reflected in the current planning and construction process, which results in wasted transportation resources and the unrealized value of land resources [13].

1.2. Built Environment Measurement Methods

The built environment, as a spatial reflection of urban design, is an important vehicle influencing the activities of residents. The 3D concept of built environment evaluation proposed by Cervero and Kockelman (1997), which categorizes the built environment into the three dimensions of density, diversity, and design, is the more classic approach [22]. They believe that the higher density, richer diversity, and better-humanized design of the built environment can reduce motorized travel mileage and inspire people to choose more public transport for travel. Later, the built environment framework of 3D was expanded to 5D, adding two more features, destination accessibility and distance to transit, to further enrich the quantification and evaluation dimensions of the built environment [23]. With the continuous use of urban big data and open data in recent years, research on the quantification of the urban built environment using spatial geographic information data analysis has been increasing based on 5D [24–26]. Zhong et al. (2020) analyzed the convenience of living within a 15-minute walk of different communities from a spatial scale, using urban points of interest (POI) as well as street network data [27]. To understand the land-use characteristics of rail transit stations in Singapore, Niu et al. (2019) used six rail transit stations in Singapore as the research objects and the ArcGIS spatial analysis. This allowed Niu et al. (2019) to study the differences in rail transit station development patterns under different TOD modes. They point out that TOD mode development should be adapted to local conditions and suggest that the composite development of rail transit stations should ensure a certain proportion of public service facilities, parks, and open spaces to achieve sustainable development of the land economy, environment, and society [28]. Moreover, it has been explained that pictures with spatial geographic information are more intuitive than data or text with only point information and can reflect the human landscape of different areas [29]. Therefore, research using street view images, combined with geographic information data, is also increasing. For example, Zhang et al. (2019) combined ArcGIS spatial analysis and street image segmentation technology from the 5D framework to quantitatively analyze the street quality in Shanghai and classified the streets into different types using the hierarchical clustering method [30]. Long and Liu (2017) used urban street view image data to compare and analyze the variability between vegetation indices of cities in different regions and at various development levels [31].
1.3. Summary

Bus terminals, like urban rail transit stations, benefit from high passenger flow and easy accessibility, and thus have the potential to be developed into TOD regions. However, the current research on TOD or land-use composite development focuses on rail transit stations rather than bus terminals. Scholars appear to be more interested in the operational efficiency of the bus terminal itself than in the land use and facilities surrounding the bus terminals. This study attempts to fill this gap. Moreover, while many empirical studies have investigated the built environment using the 3D/5D framework, the dimension of design is always critical due to the difficulty in quantifying. In this study, we aimed to measure the built environment surrounding the bus terminal, including the dimension of design, using multi-source data combined with geographic information and street view images.

2. Methods and Data

2.1. Study Area and Data

Zhengzhou, Henan Province, is an important city in the central region of China and a prominent nationally integrated transportation hub, with a resident population of about 6.5 million in its central urban area. Due to the city’s flat topography, clear road network, and high building and population density, bus lines in Zhengzhou cover a wide range of the city’s built-up area, and bus travel is an essential mode of daily travel for its citizens.

In the planning background of creating a “public transportation city”, Zhengzhou issued successive ordinances in 2021 to effectively promote the construction, renovation, and composite development of bus terminals. In the ordinance “Zhengzhou City to promote the comprehensive development of public transport terminals in the implementation of the views”, it is clearly stated that the project aims “to moderately increase the development level of the bus terminal, by the principle of balanced investment and revenue, strengthen the composite use of public transport terminals and comprehensive development, and improve land-use efficiency.” According to the document “Zhengzhou City to accelerate the construction of bus terminals implementation plan”, the city is planning to compound the development of a part of the bus terminals, gradually expand its scope, and eventually achieve the creation of all proposed bus terminals to complete the development. In Zhengzhou, the plan specifies the compound development of five pilot bus terminals: High-speed Railway Station bus terminal, Huxi Road bus terminal, Mingli Road bus terminal, Changjiang Road bus terminal, and Tengfeijie Road bus terminal. The locations of the bus stations and facilities kernel density are shown in Figure 1.

![Figure 1. Location of bus stations and facilities.](image-url)
The research data were obtained in December 2021 using the Gaode Map API and the Baidu Map API. The data on nine types of POI for restaurants, entertainment, education, and the urban road network within Zhengzhou, as well as the data of the urban road network and bus lines were obtained using the Gaode Map. The city street view image data were obtained using the Baidu Map. The basic planning information of each terminal is shown in Table 1.

Table 1. Construction plan of the five composite development bus terminals.

<table>
<thead>
<tr>
<th>Bus Terminal Name</th>
<th>Completion Time (Year)</th>
<th>Planning Area (km²)</th>
<th>Encoding</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-speed Railway bus terminal</td>
<td>2022</td>
<td>0.03</td>
<td>Terminal A</td>
</tr>
<tr>
<td>Huxi Road bus terminal</td>
<td>2022</td>
<td>0.03</td>
<td>Terminal B</td>
</tr>
<tr>
<td>Mingli Road bus terminal</td>
<td>2023</td>
<td>0.02</td>
<td>Terminal C</td>
</tr>
<tr>
<td>Changjiang Road bus terminal</td>
<td>2023</td>
<td>0.06</td>
<td>Terminal D</td>
</tr>
<tr>
<td>Tengfeijie Road bus terminal</td>
<td>2024</td>
<td>0.02</td>
<td>Terminal E</td>
</tr>
</tbody>
</table>

2.2. Research Ideas

Based on the 5D design concept, this study proposes a method that combines ArcGIS spatial analysis and machine learning semantic segmentation to measure the development environment around a bus terminal from the perspective of public transportation, focusing on two dimensions: (1) the development level and potential of the area around the bus terminal, and (2) the pedestrian environment. This study identifies seven indicators to describe the terminal’s compound development level: facility point density, functional diversity, bus route coverage, road connectivity, walking score, vegetation coverage, and road separation. The density of the first four indicators describes the level of development and development potential around the terminal. The last three indicators describe the walking environment around the terminal. The framework of the study is shown in Figure 2. Facility point density, functional diversity, bus route coverage, road connectivity, and walking scores are measured by ArcGIS spatial analysis. Vegetation coverage and road separation are obtained by element extraction of street view image data using a convolutional neural network tool (PSPnet) with a machine learning algorithm [32]. The PSPnet algorithm is one of the more widely used semantic segmentation algorithms, and this study uses a model trained by GluonCV on the Cityscapes dataset, making it more suitable for semantic segmentation of street view images.

2.3. Establishment of an Evaluation System

The scope of the study encompassed the environment within walking distance around the bus terminal. A widely accepted consensus on the definition of the walkable range for residents is the coverage of a 10-min walking time. A general walking speed of 4–5 km/h is calculated, which is equivalent to a walking distance of about 650 m–830 m. The 800 m walking distance is also commonly used as the scope of investigation in many studies on urban built environments [33,34]. Therefore, in this study, the maximum walkable range was defined as 800 m in terms of the extraction and quantification of built environment elements. The evaluation index system of this study is shown in Table 2.
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Table 2. Evaluation system.

<table>
<thead>
<tr>
<th>Perspective</th>
<th>SD</th>
<th>Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Development level and potential</td>
<td>Density</td>
<td>Facility density [30]</td>
</tr>
<tr>
<td></td>
<td>Diversity</td>
<td>Diversity of facility types [25,35]</td>
</tr>
<tr>
<td></td>
<td>Destination accessibility</td>
<td>Bus route coverage [11]</td>
</tr>
<tr>
<td>Pedestrian environment</td>
<td>Distance to transit</td>
<td>Walking score [38,39]</td>
</tr>
<tr>
<td></td>
<td>Design</td>
<td>Vegetation coverage [40,41]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Road separation [40,42]</td>
</tr>
</tbody>
</table>

Figure 2. Conceptual framework.
2.3.1. Density

The facility density is calculated by using ArcGIS to establish an 800-m buffer zone centered on the terminal location and calculating the number of POI facility points within it. POI facility points include catering services, shopping services, companies and enterprises, science, education and culture, accommodation services, healthcare, living services, business and residential, and sports and leisure. The density of facility points around a terminal reflects its current development intensity and potential, and priority should be given to low-density terminals when planning the terminal’s development.

2.3.2. Diversity

The calculation of diversity is based on the concept of “information entropy” that is used to solve the problem of quantifying information. It is now widely used to quantify land-use portfolio diversity [30,43]. The diversity is calculated by using ArcGIS to establish a buffer zone within an 800-m radius of each bus terminal and using the nine types of POI facility points mentioned above, as well as calculating the number of POI facility points within it as the research objects. The functional diversity of POI facility points around each bus terminal is then calculated. The diversity of facility points around the terminal reflects the functionality of the current surroundings of the terminal. The development should focus on the less functional terminals to improve their attractiveness.

2.3.3. Destination Accessibility

Destination accessibility is measured by the road connectivity around the bus terminal and the coverage of all the bus routes from it. Road connectivity around the bus terminal reflects the service coverage of a terminal station, while bus route coverage determines its reachability. The three indicators of the space syntax method, which are global integration, control value, and road connectivity, are used to represent road connectivity, which was calculated using Axwoman in ArcGIS [37]. The amount of POI within an area of a 500-m buffer zone along the bus route is used to depict the bus route coverage. It is calculated by using ArcGIS to calculate the number of POIs within the buffer zone of the operating routes around the yard, and then calculating the entropy of each POI and aggregating it.

2.3.4. Distance to Transit

Distance to transit can be reflected by the number of bus stops around a terminal station. The presence of several bus stops around the bus terminal indicates a more convenient bus travel environment. To evaluate the distance to transit, a conception of a walking score is introduced in this study [44]. In China, the Urban Comprehensive Transportation System Planning Standard notes that residents are more likely to accept a walking distance of 5 min or at most 10 min, and uses this as a benchmark to propose corresponding requirements for 300 m and 500 m service coverage land for public bus stops. Based on this requirement, this study determines that the best service radius for bus stops is 300 m, the effective service radius is 300–500 m, and the maximum service radius for bus stops is 800 m. The walking score of bus terminal is determined by the number and distance from the nearest bus stops. The greater the number of bus stops around the terminal and the closer the walking distance, the higher the walkability. A bus terminal with a low walking score needs to enhance the planning and management of its bus system, thus improving its development level and potential to achieve composite development.

The description of each indicator calculated using the analysis method of ArcGIS space is shown in Table 3.
Table 3. Calculation method for ArcGIS spatial analysis.

<table>
<thead>
<tr>
<th>Selected Indicator</th>
<th>Schematic Diagram</th>
<th>Indicator Description</th>
<th>Calculation Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Facility density</td>
<td><img src="image" alt="Facility density Diagram" /></td>
<td>The density of facility points around a terminal reflects its current development intensity and potential.</td>
<td>Measured by ArcGIS Buffer Analysis</td>
</tr>
<tr>
<td>Road connectivity level</td>
<td><img src="image" alt="Road connectivity Diagram" /></td>
<td>Information entropy was used to measure functional diversity. The information entropy of the number of POI in nine categories is calculated to reflect the level of functional diversity in the terminal.</td>
<td></td>
</tr>
<tr>
<td>Level of functional diversity</td>
<td><img src="image" alt="Level of functional diversity Diagram" /></td>
<td>Space syntax was used to describe three indicators: road network’s holistic concentration, control value, and connectivity. The indicators’ information entropy was used to describe the road network’s spatial relations, as well as calculate and obtain the road connectivity variable.</td>
<td>$E_i = - \ln(n)^{-1} \sum_{j=1}^{n} p_{ij} \ln p_{ij}$</td>
</tr>
<tr>
<td>Route coverage</td>
<td><img src="image" alt="Route coverage Diagram" /></td>
<td>The number of lines operated and the coverage of the lines reflect the destination accessibility of the yard station. This requires calculating the information entropy of the number of facility points covered by each line, and aggregating the lines around each field station.</td>
<td>$Q_i = \frac{E_i}{\sum_{i=1}^{k} E_i}$</td>
</tr>
<tr>
<td>Walking scores</td>
<td><img src="image" alt="Walking scores Diagram" /></td>
<td>The greater the number of bus stops around the terminal and the closer the walking distance, the higher the walkability. The distance from terminals to bus stops is calculated by ArcGIS network analysis.</td>
<td>$w = \sum w_i$ for $l \leq 300 \text{ m}$; $w_i = 1$ for $300 &lt; l \leq 500 \text{ m}$; $0.5 \leq w_i &lt; 1$ for $500 &lt; l \leq 800 \text{ m}$; $0 \leq w_i &lt; 0.5$</td>
</tr>
</tbody>
</table>

In which $i$ is the index of sample attribute; $j$ is the index of sample; $p_{ij}$ is the proportion of attribute $j$ in sample $i$; $n$ is the number of samples; $E_i$ is the information entropy of the $i^{th}$ index; $k$ is the number of indicators; $Q_i$ the weight of the $i^{th}$ indicator. $w_i$ is the walking score from a single bus stop to the terminal; $w$ is the total walking scores for that terminal.

2.3.5. Design

The design dimension should be reflected through the visual landscape of the street space, including the indicators of vegetation coverage, sky visibility, and spatial openness. Existing studies have provided evidence that more plant and sky can make people more willing to stay outdoors. As a component of quality of life, vegetation coverage is vital for oxygen production, pollutant absorption, and urban heat island effect mitigation [2]. Further, better road separation is good for better pedestrian safety, and it improves people’s pleasure when walking [45].

Street view images are collected from Baidu LBS. Firstly, the locations where to grab the street view image are generated along the road network within the buffer area surrounding the bus terminals at an interval of 150 m. Then, images are acquired for each point at four angles (90°, 180°, 270°, 360°) at one location, with a specific latitude and longitude. Finally, a total of 2508 street view images were extracted within an 800-m coverage scope of five
bus terminals. Then, the machine vision technology is adopted to analyze the street view images. The flowchart of data collection and analysis is shown in Figure 3. In this study, we used the PSPnet model, which is a semantic segmentation algorithm, to extract details in street view images. Two indicators of vegetation coverage and road separation are constructed to represent the design dimension. The performance of the two indicators in actual scenarios is shown in Table 4. The vegetation coverage is obtained by calculating the percentage of vegetation coverage in the image. The road separation coverage is calculated as the sum of the percentages of buildings, walls, and fences in the image.

![Flowchart of street view image collection and analysis.](image)

**Figure 3.** Flowchart of street view image collection and analysis.

<table>
<thead>
<tr>
<th>Index</th>
<th>Example</th>
<th>Vegetation Coverage</th>
<th>Road Separation</th>
</tr>
</thead>
<tbody>
<tr>
<td>More vegetation</td>
<td><img src="image" alt="More vegetation" /></td>
<td>0.454</td>
<td>0.014</td>
</tr>
<tr>
<td>Less vegetation</td>
<td><img src="image" alt="Less vegetation" /></td>
<td>0.134</td>
<td>0.096</td>
</tr>
<tr>
<td>Better road separation</td>
<td><img src="image" alt="Better road separation" /></td>
<td>0.221</td>
<td>0.133</td>
</tr>
<tr>
<td>Worse road separation</td>
<td><img src="image" alt="Worse road separation" /></td>
<td>0.184</td>
<td>0.019</td>
</tr>
</tbody>
</table>

**3. Results**

The calculation results of the evaluation index based on the 5D framework are shown in Table 5. The index of facility density reflects the density dimension. Terminal C has the highest facility density index, indicating that its surroundings are more developed than those of the other terminals. The Terminal B area is still being developed, as evidenced by the index of facility density.
Table 5. Calculation of evaluation index.

<table>
<thead>
<tr>
<th>Index (5D Framework)</th>
<th>Terminal A</th>
<th>Terminal B</th>
<th>Terminal C</th>
<th>Terminal D</th>
<th>Terminal E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>Facility density</td>
<td>450</td>
<td>82</td>
<td>1151</td>
<td>486</td>
</tr>
<tr>
<td>Diversity</td>
<td>Functional diversity</td>
<td>0.28</td>
<td>0.05</td>
<td>0.89</td>
<td>0.32</td>
</tr>
<tr>
<td>Destination accessibility</td>
<td>Bus route coverage</td>
<td>18.95</td>
<td>1.52</td>
<td>3.35</td>
<td>6.03</td>
</tr>
<tr>
<td></td>
<td>Road connectivity</td>
<td>7.05</td>
<td>0.51</td>
<td>2.95</td>
<td>5.61</td>
</tr>
<tr>
<td>Distance to transit</td>
<td>Walking score</td>
<td>23.39</td>
<td>3.53</td>
<td>14.14</td>
<td>18.99</td>
</tr>
<tr>
<td>Design</td>
<td>Vegetation coverage</td>
<td>0.08</td>
<td>0.22</td>
<td>0.23</td>
<td>0.12</td>
</tr>
<tr>
<td></td>
<td>Road separation</td>
<td>0.23</td>
<td>0.15</td>
<td>0.10</td>
<td>0.17</td>
</tr>
</tbody>
</table>

The functional diversity index of facilities described the diversity dimension of the built environment. Terminal C has the highest diversity index, while Terminal B has the lowest. The development level of station C is referred to as being relatively higher than other terminals, and as a result, the potential demand for bus travel is higher; however, the nearby facilities of station B are not only low in density but also less in type, and there is still a gap from compound development.

The dimension of destination accessibility is represented by two indexes: bus route coverage and road connectivity. The findings show that Terminal A is more accessible than the others, while Terminal B is the least accessible. The dimension of destination accessibility represents the foundation of transportation infrastructure, which is an important factor in determining the potential of future compound development.

The walking score, or distance to transit index, reflects the convenience of pedestrians walking to transit. Bus terminals A, C, and D provide superior walkability for bus passengers, implying greater potential for use of facilities surrounding the terminals.

The design dimension includes two indexes of vegetation coverage and road separation in this study, which describe the quality of walking space and the walking safety, respectively. Terminal A has the highest road separation value but the lowest vegetation coverage, whereas Terminal C has the highest vegetation coverage but the lowest road separation. Terminals B and C have more vegetative cover than the other three terminals.

Terminal A’s bus route coverage and road connectivity are significantly greater than those of other terminals. This indicates that Terminal A has a significant impact within the city of Zhengzhou, despite the fact that the current facility density and functional diversity are not significantly greater than those of other field stations; hence, the potential for development is large. At the same time, the area’s vegetation coverage is poor, and further development will exacerbate environmental pollution. Thus, Terminal A exhibits a perceived weakness in walking quality, implying that more attention should be paid to the walking space to attract more pedestrians and increase the potential for composite development.

There is still a gap in compound development in Terminal B, because the nearby facilities are not only low in density but also in type. Furthermore, Terminal B’s road connectivity, bus route coverage, and walking score are all poor, which is a significant factor in the terminal’s development potential. Therefore, from the perspective of area planning, Terminal B should first improve its road network in order to prepare for intensive development.

The facility density and functional diversity in Terminal C were higher than in the other terminals, indicating that the facilities surrounding it are already relatively well-developed. However, the bus route coverage and road connectivity around Terminal C are inadequate, and more road and route improvements are required to improve Terminal C’s attractiveness. Meanwhile, we discovered that Terminal B’s road separation is inadequate, and there is a need to improve Terminal C’s walls and fences to improve people’s perception of walking safety.

Terminal D and Terminal A developed in a similar manner. However, Terminal D’s bus route coverage and road connectivity are not as good as Terminal A’s. As a result,
further bus route planning in Terminal D is required to increase its attractiveness within
Zhengzhou. After construction is completed in 2023, this terminal is expected to open in
2024. Once operational, the development intensity of the surrounding area is expected to
increase further as urbanization progresses.

Terminal E had higher facility density but lower functional diversity, indicating that
it only has a single functional structure and that the terminal requires further functional
improvement. It also has a low walking score and road connectivity; as a result, the
land-use development strategy should be given more attention during the planning and
construction processes, balancing the spatial distribution of various land-use functions.

4. Discussion

Using a quantitative analysis of the spatial relationships of the facilities surrounding
these public terminals, this study proposed an index system to effectively evaluate the
compound development of bus terminals. This was a new exploration in the context of
digital urban design from the perspective of public transit and land utilization. Unlike
previous terminal optimization studies, this study focused on the built environment sur-
rounding bus terminals rather than bus route planning and bus operation efficiency [20,21].
This study analyzed the inadequacy in bus terminal composite development from the
perspectives of the current situation, composite development potential, and pedestrian
friendliness, and also put forward suggestions for future development. This study de-
viated even further from previous studies by employing both geographic information
and street view images to evaluate the bus terminal and the surrounding built environ-
ment [10,46,47]. In addition, to quantify the pedestrian environment, this study used
machine vision semantic segmentation.

In the context of rapid urbanization, urban public transportation is a key concern of
the government to serve and promote the efficient development of the urban economy
and society, as well as to provide residents with an economical and convenient mode of
transportation. Currently, the terminal construction model in China can be described as a
government-led model: the government allocates land to bus companies for the construc-
tion of terminals at no cost, and, in many cases, with certain subsidies. The bus company is
then in charge of building the terminals, and once completed, the admission of vehicles
operating on all bus routes is reallocated to achieve the lowest total cost vehicle admission
scheme. Despite these conditions, the station is still operating at a loss. Meanwhile, the
construction of the terminal requires encroaching on a large amount of urban land, resulting
in a large amount of wasted land resources.

The significance of strengthening the compound development and construction of
terminals is fivefold. It reduces the government’s financial allocation that is constantly
allocated to terminals and relieves financial pressure. The TOD used in the terminal’s
construction increases the land value of the area where the terminal is located as well as the
terminal’s financial revenue. The wider coverage of the bus line network improves travel
convenience for city residents, while the accessibility of residential housing developed
around the terminal based on bus-oriented development is good and less expensive than the
central area, providing new residential options. Improving land use around Zhengzhou can
also effectively relieve agglomeration pressure in the city center in terms of urban planning.
In terms of the built environment, an effective assessment of a terminal’s development
potential and development environment based on the terminal itself, as well as a refined
optimization strategy for the terminal environment, can assist the government and transit
authorities in proposing various development options for different terminals.

5. Conclusions

This study’s innovation is the effective integration of machine-learning technology and
geographic information technology, which expanded and enriched the built environment
evaluation. This study proposed a method for evaluating the spatial relationship among
facilities surrounding bus terminals by combining urban points-of-interest and street
view image data from two perspectives: the terminals’ current level of development and potential, and an evaluation of the surrounding pedestrian environment. The results showed the composite development status and potential of the planned bus terminals in the city of Zhengzhou, and the discussion of the results provided practical implications to support the bus terminal composite development strategy.

The following are the main contributions of the study. First, this study presents an applicable method to evaluate transportation terminal areas based on open data and government-issued documents. Second, the study demonstrates how basic geographic information and street view image data can be used to study the three-dimensional spatial characteristics of specific urban areas. Third, this study proposes an evaluation method from two perspectives: the current development level and potential of the composite development bus terminal, and the pedestrian environment surrounding the bus terminals. This evaluation is expected to support the bus terminal composite development strategy.

From the results, the quantitative evaluation can truly and accurately reflect the current situation, but some technical aspects still need to be improved. For instance, the street view image is only one component of an indication of the walking quality of a street; other factors such as voice and air quality also influence walking quality. Furthermore, only quantifiable physical characteristics were analyzed in this study. The perspective and willingness of the travelers were not considered. Based on the quantitative evaluation, willingness surveys and behavior data collection may help improve the evaluation. To improve accuracy and comprehensiveness, more multi-source data can be incorporated into future assessments of composite development regions. As information technology advances, aspects related to environmental quality, such as user perception, preference, willingness, and other qualities, can also be taken into account.

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