

# SPATIAL INTERACTION ANALYSIS OF URBAN FUNCTIONAL DISTRICTS BASED ON TAXI TRAJECTORIES

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## ABSTRACT:

The functional differences among various components of a city drive the circulation of logistics, human flows, and energy flows within the city. Qualitatively and quantitatively analyzing the spatial interactions among urban functional districts contributes to understanding the spatial structure of it and formulating more efficient urban planning strategies. Based on taxi trips, this paper compares spatial interactions between the Xudong Commercial District and the Zhongnan Road Commercial District in Wuhan, respectively, with other functional districts. Firstly, the spatial interaction based on taxi trips between these two commercial districts, acting as either the origins or destinations for taxi trips, with various functional districts was visualized. Subsequently, we analyzed the intensity and distance of the spatial interactions based on taxi trips during each typical time period (8:00-9:00, 18:00-19:00, and 20:00-21:00 on weekdays; and 9:00-10:00, 19:00-20:00, and 22:00-23:00 on weekends). These results can serve as reference for further research on the influence range, development planning, and transportation optimization of these commercial districts.

## 1. INTRODUCTION

Urban functional districts refer to residential districts, commercial districts, industrial districts, as well as other functional districts gradually formed in the urban development. Studying the spatial distribution patterns of different types of functional districts and the interaction laws between them are of great significance for improving urban land use efficiency, optimizing the resource allocation, and establishing the scientific and reasonable policy of urban planning.

Using residents' travel patterns from taxi trajectories to analyse the spatial interaction between different urban functional districts have been widely studied (Chen et al., 2017; Ge et al., 2019; Liu et al., 2016; Pan et al., 2013; Wang et al., 2018; Xu et al., 2022). Some researchers clustered taxi trajectories to extract hot spots and analysed the spatial interaction between them. Some extracted features from taxi trajectories to identify urban functional districts. Our previous work (Zhang et al., 2022) has compared the effectivity of seven most-used time series statistics of taxi pick-up and drop-off points, and selected the best combination of statistics to identify different types of urban functional districts (commercial district, mixed-use district, industrial district, residential district, and central Commercial District) of Wuchang District, Wuhan. The analysis units were constructed based on the OpenStreetMap (OSM) road network, and were refined by taxi trajectories. To explore the idea further, this paper used taxi trips to analyse the spatial interaction between the above identified functional districts

during each typical time period, which include 8:00-9:00, 18:00-19:00, and 20:00-21:00 on weekdays, as well as 9:00-10:00, 19:00-20:00, and 22:00-23:00 on weekends. Taking two traditional Commercial Circles as examples, this study compared the intensity and distance of the spatial interaction between them and many other functional districts, respectively.

## 2. STUDY AREA AND DATASET

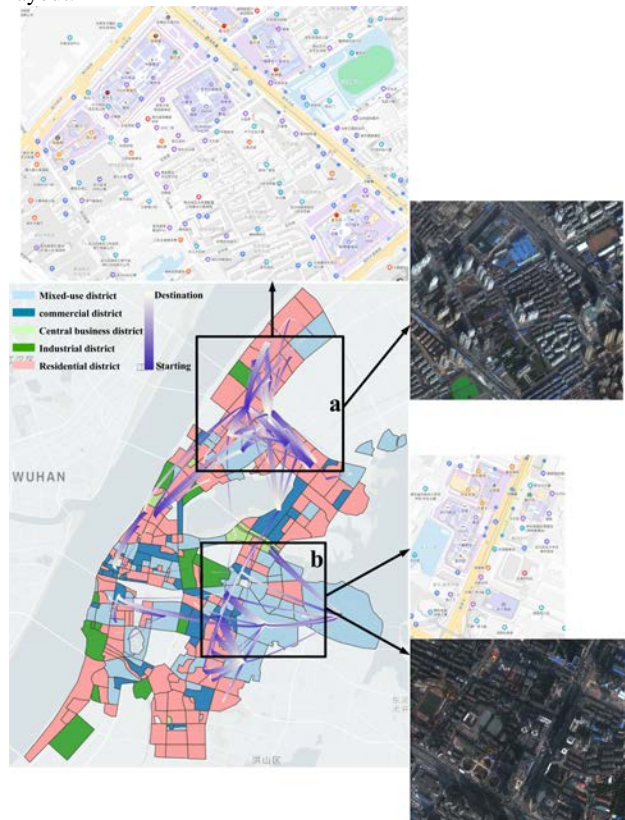
### 2.1 Study Area

Xudong Commercial District and Zhongnan Road Commercial District are two popular Commercial Districts in Wuchang District, Wuhan, Hubei, China. Figure 1 shows the spatial distribution of Xudong Commercial District (shown in Box a) and Zhongnan Road Commercial District (shown in Box b) in Wuchang District. The electronic map in Figure 1 was captured from Baidu Online Maps and the remote sensing imagery was obtained by Pleiades-1 high-spatial-resolution satellite.

Xudong Commercial District is located on Xudong Street, which is a major urban artery connecting Wuchang and Hankou and serves as a gateway to the Second Yangtze River Bridge. The district benefits from good road accessibility. It houses numerous large department stores, supermarkets, and home furnishing malls, providing a wide range of dining, entertainment, and leisure facilities to cater to the surrounding areas, which are primarily residential districts. It's a relatively single-function district. Zhongnan Road Commercial District is

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situated in the core area of the inner ring of Wuchang District and is one of the earliest core Commercial Districts in Wuhan. It extends northward along Zhongbei Road to Hongshan Square and borders emerging commercial districts such as Wuluo Road and Jiedaokou to the east along Wuluo Road. The district is positioned at the intersection of Metro Line 2 and Line 4, enjoying good road accessibility. However, it is not convenient to take taxis directly in front of the major department stores and malls in this district. Therefore, the research area selected for the Zhongnan Road Commercial District in this experiment is a functional block adjacent to Hongshan Square and Yamao. The district is primarily composed of large department stores, supermarkets, electronic appliance retailers, and office buildings, positioning itself as an urban complex for commerce, shopping, entertainment, dining, and leisure. In June 2020, the launch of the "Zhongnan Road Commercial District Alliance," hosted by the Wuchang District People's Government, provided strong support for the recovery and rise of Zhongnan Road Commercial District as the core commercial center of Wuchang (Liu, 2020). The district is surrounded by numerous enterprises, institutions, and government agencies, and it is accompanied by popular residential areas such as Lidao 2046 and Bairuijing Central Living Area, resulting in a more complex functional layout.



**Figure 1.** Spatial distribution map of Xudong Commercial District and Zhongnan Road Commercial District in Wuchang District.

## 2.2 Dataset

### 2.2.1 Taxi Trajectories

The original taxi trajectories were collected from February 1<sup>st</sup> to August 10<sup>th</sup>, 2015. The sampling interval is less than one minute. Each record contains the following information: the ID of the taxi, the timestamp, longitude, latitude, the instantaneous driving direction, the driving speed, the Advanced Cruise Control (ACC), the taxi operation status and the vacant statue.

The detailed preprocessing of taxi trajectories has been described in our previous work (Zhang et al., 2022), and is not the main focus of this paper.

### 2.2.2 OpenStreetMap Road Network

OSM data is a freely available open-source world map and the road network within it has been proved be well-utilized defining urban blocks urban land use analysis (Zhang et al., 2017). Although grid-based division methods are more convenient and can improve computational speed, they tend to disrupt the natural environment's parcel divisions. Compared to regular grids, analysis units based on urban blocks better align with human cognition of real space. We downloaded OSM data of the Wuhan region in 2015 from the official website. The data was then converted into shapefile format using ArcGIS tools. The road vector layer was primarily utilized to generate a basic road map for the purpose of defining the boundaries of urban functional districts, which serve as the fundamental analysis units. The detailed procedures of analysis units construction has been described in our previous work (Zhang et al., 2022), and is not the main focus of this paper.

## 3. EXPERIMENT

After conducting numerous experimental analyses, this paper has selected several specific time periods, 8:00-9:00, 18:00-19:00, and 20:00-21:00 on weekdays; 9:00-10:00, 19:00-20:00, and 22:00-23:00 on weekends, to compare the differences of spatial interactions based on taxi trips between Xudong Commercial District and Zhongnan Road Commercial District and various functional districts, separately. First, the spatial interaction between the two typical commercial districts and various functional districts was visualized by the open-source tool kepler.gl. Then, calculating the number of taxis originating from or heading to the two commercial districts, serving as indicators to measure their spatial interaction intensity. Lastly, calculating the average geographic distance of the origins and destinations of taxi trips between the two commercial districts with other functional areas to measure their spatial distance.

### 3.1 Analysis of the Intensity and Distance of Spatial Interaction between Xudong Commercial District and Various Functional Districts

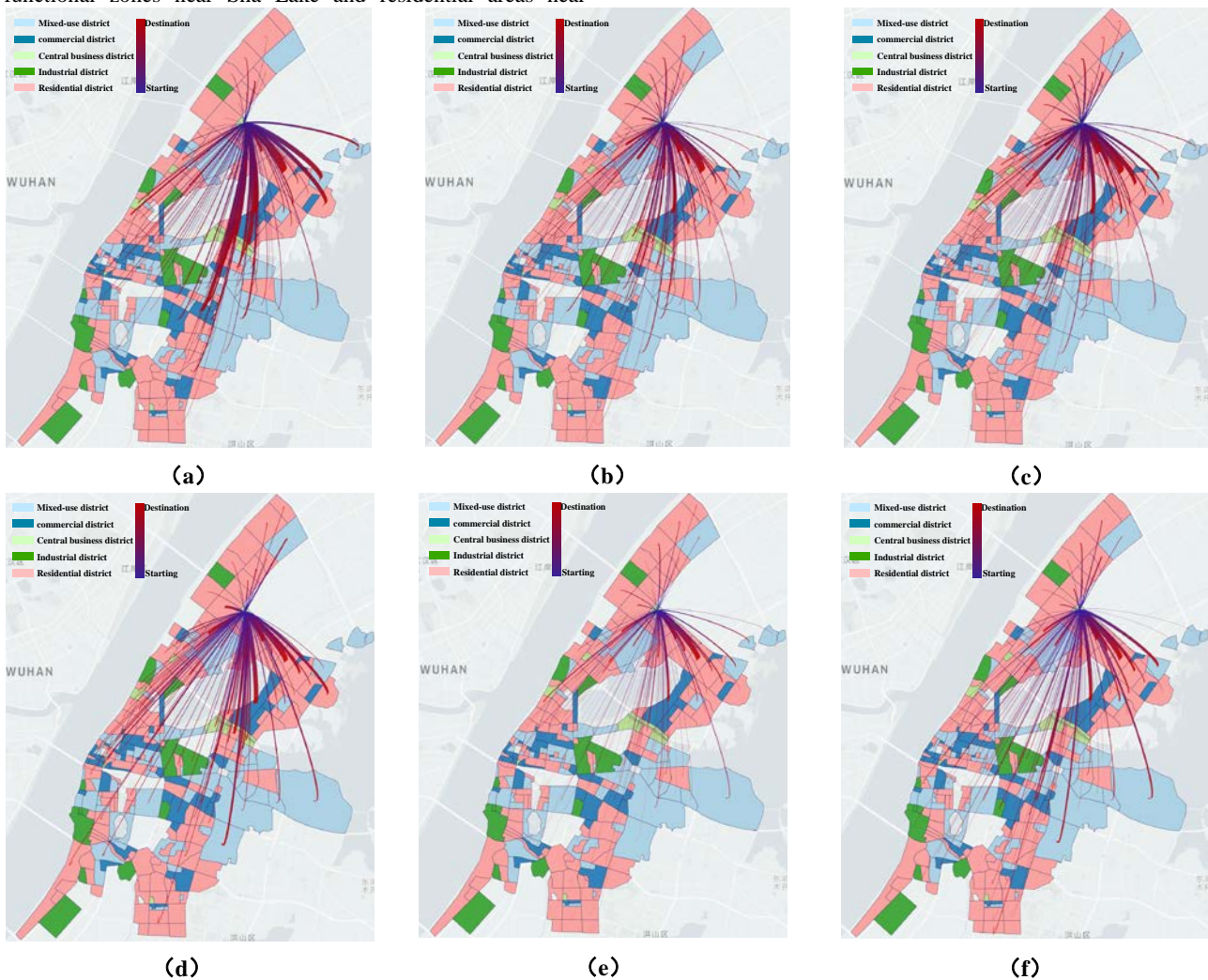
#### 3.1.1 Xudong Commercial District as the Origin for Taxi trips

Figure 2 shows the spatial interaction between Xudong Commercial District, as the origin, and other functional districts in Wuchang District. The gradient color curve represents the taxi trips, with the deep purple end representing the origin and the red end representing the destination. The width of the curve represents the volume of taxi trips between the two functional districts, indicating the intensity of spatial interaction.

From Figure 2, it can be observed that: 1) the majority of taxi trips originating from Xudong Commercial District, except during the time period between 8:00 and 9:00 on weekdays, primarily end in the functional districts near Sha Lake. However, a relatively smaller number of trips end in the residential districts located in the northern part of Wuchang district. 2) The destinations of the taxi trips are mainly concentrated between Sha Lake and East Lake. 3) The volume of taxi trips is significantly higher on weekdays than on weekends, with the widest coverage during the morning rush hour between 8:00 and 9:00.

In summary, Xudong Commercial District exhibits a relatively high intensity of spatial interaction with various functional zones in the Wuchang district, primarily concentrated in the functional zones near Sha Lake and residential areas near

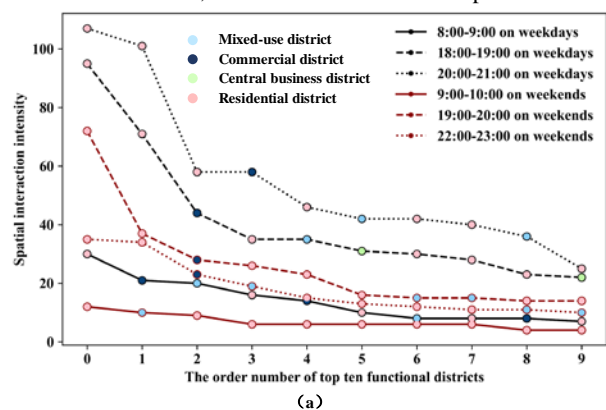
Donghu. The spatial interaction is more pronounced during weekday mornings and weekend evenings,

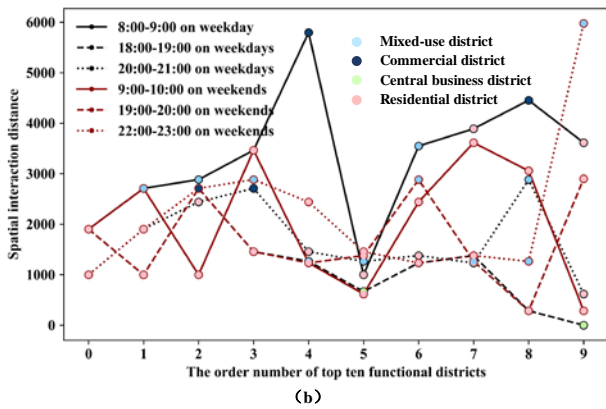


**Figure 2.** Spatial interaction between Xudong Commercial District (as the origin) and other functional areas during typical time periods, including: (a) Weekday 8:00-9:00, (b) Weekday 18:00-19:00, (c) Weekday 20:00-21:00, (d) Weekend 9:00-10:00, (e) Weekend 19:00-20:00, and (f) Weekend 22:00-23:00.

Figure 3 illustrates the intensity and distance of the spatial interaction based on taxi trips of top ten functional districts with Xudong Commercial Circle as the origin during typical time periods. Overall, the destinations of taxi trips on weekdays include residential, commercial, mixed-use, and central commercial districts. While, on weekends, the destinations primarily consist of residential, commercial and mixed-use districts, with residential areas being the majority. Figure 3 (a) reveals that: the overall volume of taxi trips is higher on weekdays compared to weekends. The lowest taxi trips volumes occur during the time periods between 8:00 and 9:00 on weekdays and between 9:00 and 10:00 on weekends. The total travel volume to the four types of destinations (residential, commercial, mixed-use, and central commercial districts) decreases on weekdays. Figure 3 (b) shows that 1) The majority of taxi trips distances fall within the range of 1000-4000 meters, with shorter travel distances on weekends concentrated within 3000 meters. 2) The reaching residential districts are relatively close, while the commercial and mixed-use districts are farther

away. This aligns with the actual situation near Xudong Commercial District, where residential areas are predominant.





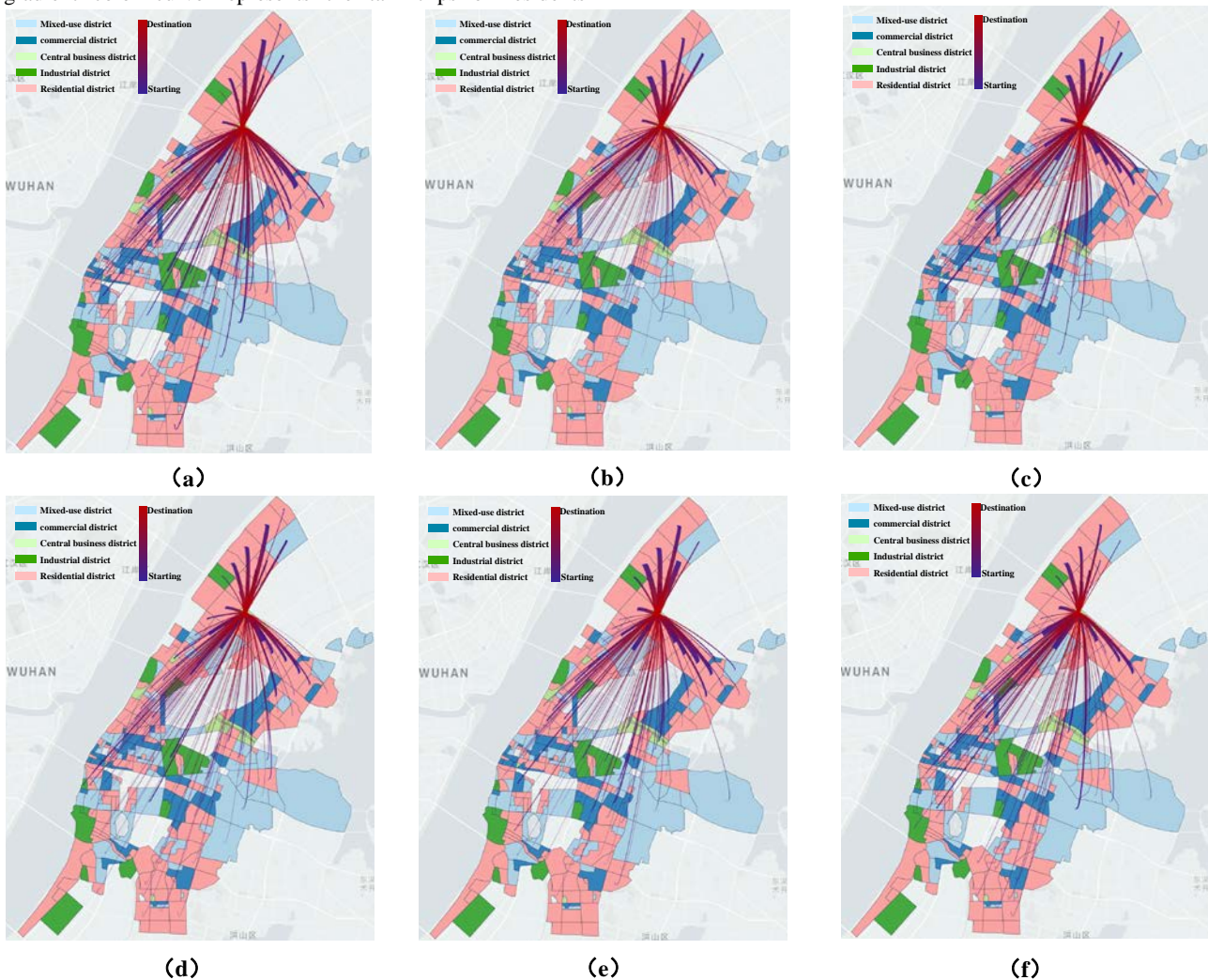
**Figure 3.** Analysis of spatial interaction based on taxi trips of top ten functional districts with Xudong Commercial Circle as the origin.

### 3.1.2 Xudong Commercial District as the Destination for Taxi trips

Figure 4 shows that the spatial interaction between Xudong Commercial District, as the destination, and other functional districts in Wuchang District during typical time periods. The gradient color curve represents the taxi trips of residents

between these two city functional districts. The deep purple end of the curve represents the origin, while the red end represents the destination. The width of the curve represents the magnitude of taxi trips between them, indicating the intensity of spatial interaction. As shown in Figure 4, taxi trips predominantly originate from neighboring functional districts. Moreover, the residential districts in the northern part of Wuchang District is strongly attracted to Xudong Commercial District. Apart from the time period between 22:00 and 23:00 on weekends, the total number of residents from the northern part of Wuchang District alighting at Xudong Commercial District dominates compared to other residential districts during other time periods. From a spatial perspective, residents taking taxis to Xudong Commercial District are mainly concentrated north of Sha Lake, with fewer residents coming from the southern residential areas of Sha Lake.

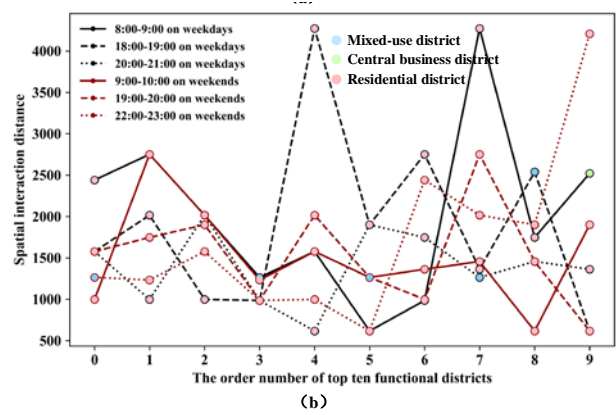
Overall, these findings shed light on the spatial interactions and taxi trips patterns between Xudong Commercial District and other functional districts in Wuhan, particularly highlighting the strong attraction of Xudong Commercial District to residents from the nearby residential districts and the concentration of taxi trips from the northern part of Wuchang District.



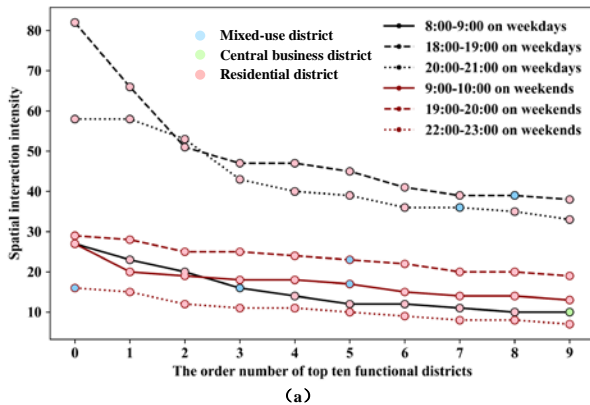
**Figure 4.** Spatial interaction between Xudong Commercial District (as the destination) and other functional areas during typical time periods, including: (a) Weekday 8:00-9:00, (b) Weekday 18:00-19:00, (c) Weekday 20:00-21:00, (d) Weekend 9:00-10:00, (e) Weekend 19:00-20:00, and (f) Weekend 22:00-23:00.

Figure 5 describes the intensity and distance of the spatial interaction based on taxi trips of top ten functional districts with Xudong Commercial Circle as the destination during typical time periods. Overall, residents who travel to Xudong Commercial District on weekdays and weekends come from three types of functional districts: residential, mixed-use, and central commercial districts, with residential areas comprising the majority.

More specifically, Figure 5(a) reveals that: 1) The taxi trips volume on weekdays is generally higher than on weekends. 2) The period between 8:00 and 9:00 on weekdays has the lowest taxi trips volume, while the period between 22:00 and 23:00 on weekends has the lowest volume. Figure 5(b) reveals that: 1) The taxi trips distance to Xudong Commercial District is mainly concentrated between 1000 and 3000 meters, with the weekend travel distance primarily within 2500 meters. 2) Taxi trips originating from residential districts to Xudong Commercial District have a larger range of taxi trips distances than mixed-use and central commercial districts, ranging from 500 to 5000 meters.



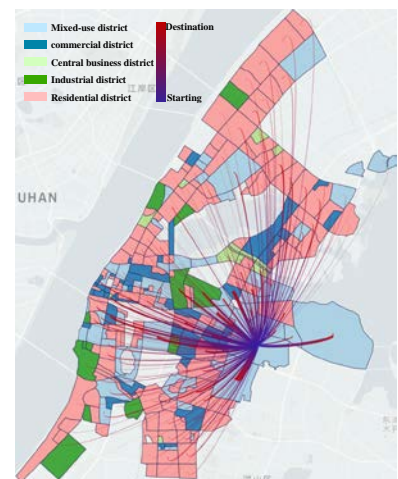
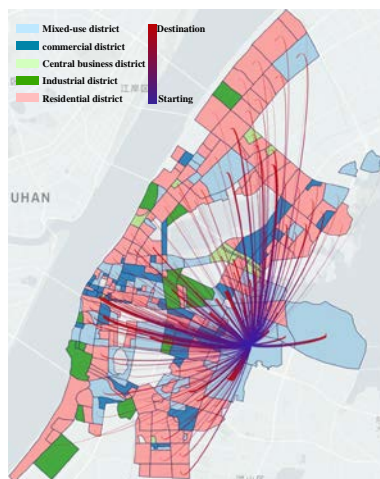
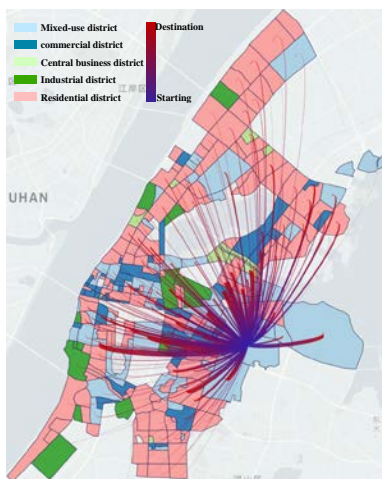
**Figure 5.** Analysis of spatial interaction based on taxi trips of top ten functional districts with Xudong Commercial Circle as the destination.



### 3.2 Analysis of the Intensity and Distance of Spatial Interaction between Zhongnan Road Commercial District and Various Functional Districts

#### 3.2.1 Zhongnan Road Commercial District as the Origin for Taxi trips

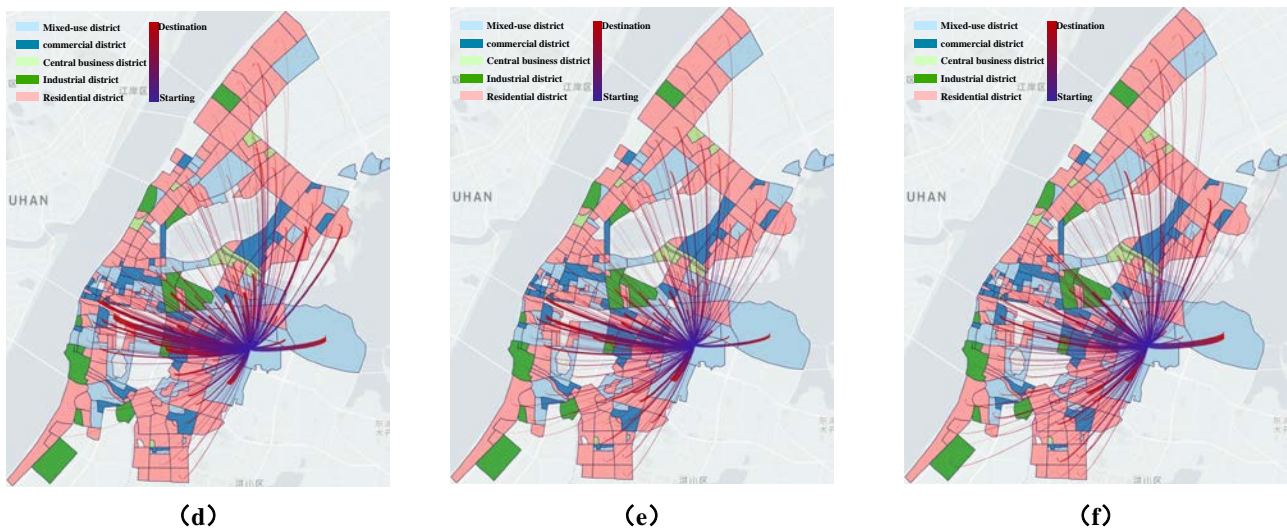
Figure 6 shows the spatial interaction between Zhongnan Road Commercial District, as the origin, and other functional districts in Wuchang District during typical time periods. The gradient curve represents the taxi trips of residents between two urban functional districts. The deep purple end of the curve represents the origin, while the red end represents the destination. The width of the curve represents the volume of taxi trips between the two functional districts, indicating the intensity of spatial interaction. Figure 6 demonstrates the extensive coverage of taxi trips from Zhongnan Road Commercial District throughout the Wuchang District and the consistency of this coverage between weekdays and weekends.



(a)

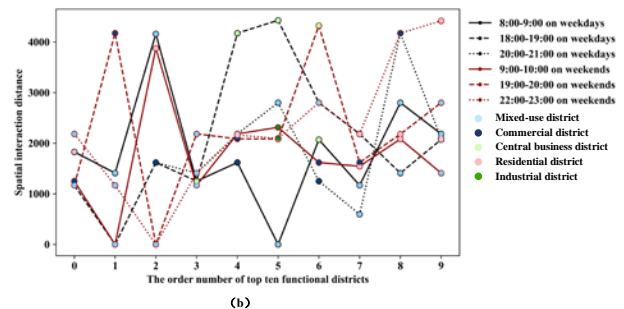
(b)

(c)



**Figure 6.** Spatial interactions between the Zhongnan Road Commercial District (as the origin) and other functional districts during typical time periods, including: (a) Weekday 8:00-9:00, (b) Weekday 18:00-19:00, (c) Weekday 20:00-21:00, (d) Weekend 9:00-10:00, (e) Weekend 19:00-20:00, and (f) Weekend 22:00-23:00.

Figure 7 illustrates the intensity and distance of the spatial interaction based on taxi trips of top ten functional districts with Zhongnan Road Commercial Circle as the origin during typical time periods. In terms of the overall pattern, the destinations of taxi trips from Zhongnan Road Commercial District encompass all five types of functional districts, including mixed-use, commercial, central commercial, residential, and industrial districts. The major destination are observed to be in mixed-use and commercial districts, and there is no specific concentration of these taxi trips in any particular type of functional district. Figure 7 (a) shows that on weekdays, the total volume of taxi trips is slightly higher than on weekends. During weekdays, the hour between 18:00 and 19:00 experiences the lowest volume of taxi trips, while on weekends, the hour between 19:00 and 20:00 has the lowest volume. Figure 7 (b) demonstrates that 1) the range of taxi trips distances from Zhongnan Road Commercial District falls under 4500 meters. The majority of these taxi trips are concentrated within a distance of 3000 meters. 2) There is no significant difference in taxi trips distances between weekdays and weekends. 3) Taxis arriving at Zhongnan Road Commercial District show clear signs of internal travel within the district.

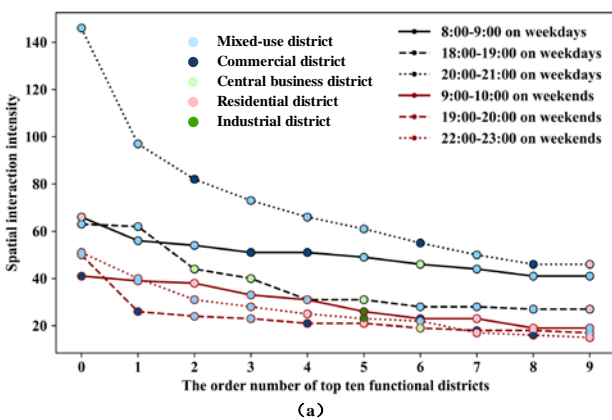


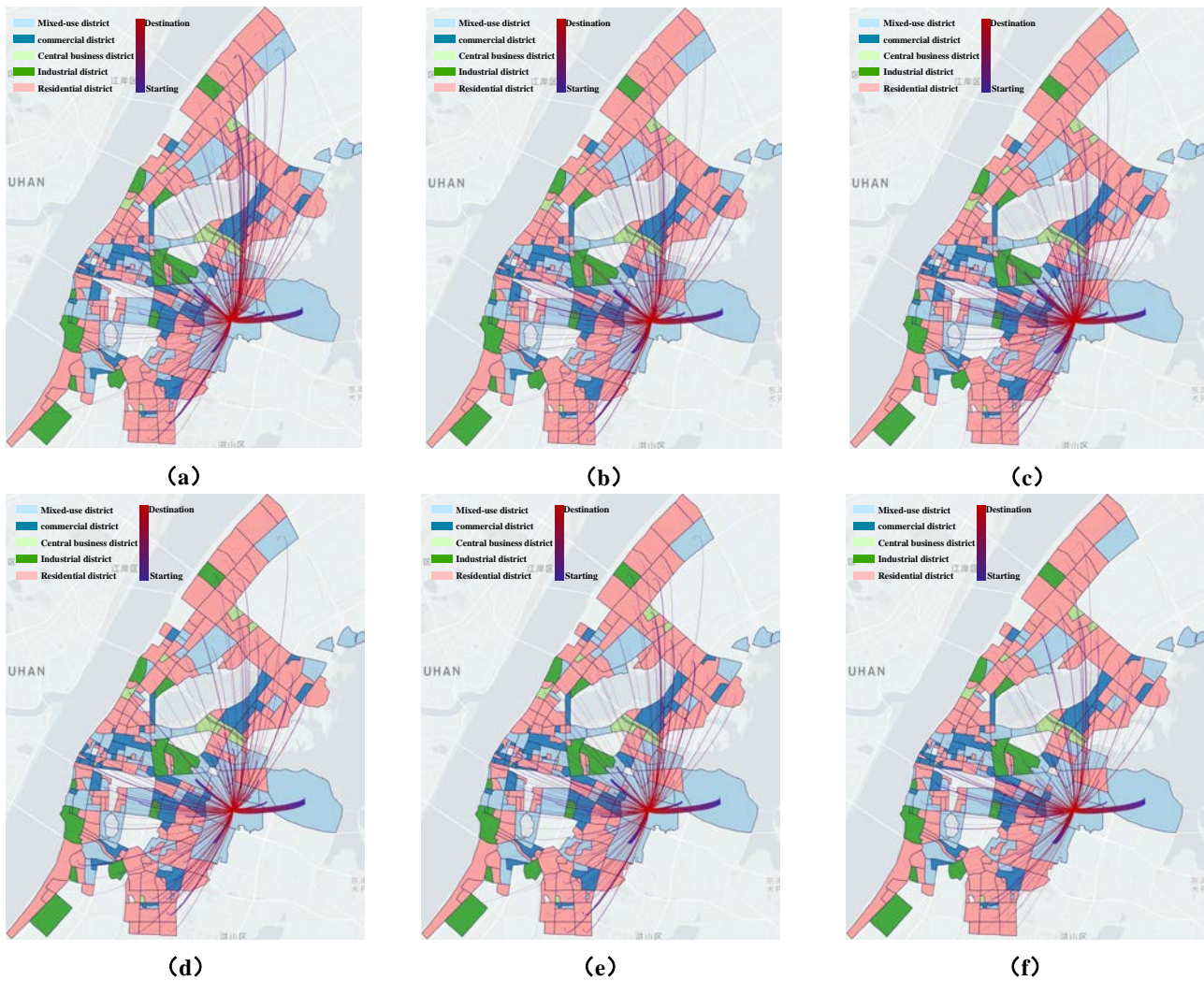
**Figure 7.** Analysis of spatial interaction based on taxi trips of top ten functional districts with Zhongnan Road Commercial Circle as the origin.

### 3.2.2 Zhongnan Road Commercial District as the Destination for Taxi trips

Figure 8 shows the spatial interaction between Zhongnan Road Commercial District, as the destination, and other functional districts in Wuchang District during typical time periods. The gradient-colored curves represent the taxi trips patterns of residents between two functional districts within the city. The deep purple end of the curve represents the origin, while the red end represents the destination. The width of the curve indicates the volume of taxi trips between the two functional districts, representing the intensity of spatial interaction.

Figure 8 shows that 1) residents taking taxis to the Zhongnan Road Commercial District cover almost the entire Wuchang District, with the majority concentrated in the functional areas south of Hongshan Square and north of Sha Lake. There are very few residents taking taxis from functional districts outside this region to the Zhongnan Road Commercial District. 2) The coverage of taxi trips to the Zhongnan Road Commercial District does not appear to differ significantly between weekdays and weekends.

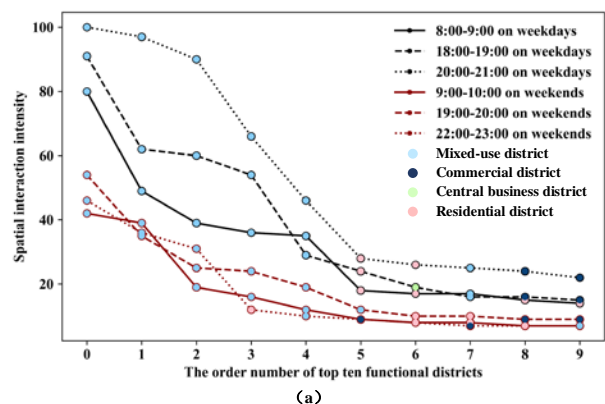


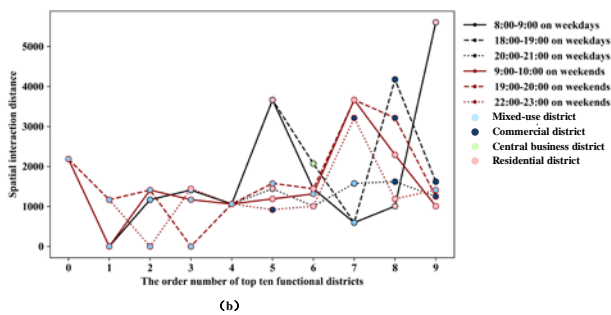


**Figure 8.** Spatial interaction between Zhongnan Road Commercial District (as the destination) and other functional areas during typical time periods, including: (a) Weekday 8:00-9:00, (b) Weekday 18:00-19:00, (c) Weekday 20:00-21:00, (d) Weekend 9:00-10:00, (e) Weekend 19:00-20:00, and (f) Weekend 22:00-23:00.

Figure 9 illustrates the intensity and distance of the spatial interaction based on taxi trips of top ten functional districts with Zhongnan Road Commercial Circle as the destination during typical time periods. The origins of taxi trips to the Zhongnan Road Commercial District belong to four types of functional districts: mixed-use, commercial, residential, and commercial districts. Among them, the highest volume of taxi trips to the Zhongnan Road Commercial District originates from mixed-use district. Figure 9 (a) reflects that: 1) the volume of taxi trips to is generally higher on weekdays compared to weekends. 2) The volume of taxi trips from mixed-use, residential, and commercial districts to the Zhongnan Road Commercial District decreases in that order. Figure 9 (b) shows that: 1) the taxi trips distance to the Zhongnan Road Commercial District is mainly concentrated within 3000 meters. 2) The taxi trips distance from the top four functional districts to the Zhongnan Road Commercial District during typical time periods is mostly less than 2000 meters, and there are frequent internal travels within the Zhongnan Road Commercial District.

In summary, Figure 9 provides insights into the top ten functional districts with the highest taxi trips volume to the Zhongnan Road Commercial District.





**Figure 9.** Analysis of spatial interaction based on taxi trips of top ten functional districts with Zhongnan Road Commercial Circle as the destination.

#### 4. DISCUSSION

This paper qualitatively and quantitatively analyzed the spatial interactions and distances between two major popular commercial districts and other functional districts during typical time periods. Results show that the available coverage of Zhongnan Road Commercial Circle is larger than that of Xudong Commercial Circle overall. The taxi trips activities of Xudong Commercial Circle are more concentrated, mainly to the north of Sha Lake. Specifically, 1) considering the types of interactive functional districts, most of top ten functional districts that have frequent spatial interaction with Zhongnan Road Commercial Circle are mixed-use districts or commercial districts, while the majority of top ten functional districts having frequent spatial interaction with Xudong Commercial Circle are residential districts. 2) The difference of the spatial interaction intensity of taxi trips of Zhongnan Road Commercial Circle between weekdays and weekends is smaller than that of Xudong Commercial Circle, and both numbers of taxi trips of the two Commercial Circles on weekdays are higher than that on weekends. 3) When discussing the spatial interaction distance, there is an obvious internal travel pattern in Zhongnan Road Commercial Circle.

#### 5. CONCLUSIONS

Taking Xudong Commercial District and Zhongnan Road Commercial District as examples, this study compared the spatial interaction intensity and distance between them and other functional districts in Wuchang District during typical time periods. Based on taxi trips, we compared the distance and intensity of the spatial interaction between Xudong Commercial Circle and Zhongnan Road Commercial Circle with other urban functional districts, respectively. Overall, analyzing the spatial interactions and distances of the spatial interaction between these two commercial districts and other functional districts provides valuable insights into their characteristics and dynamics, help managing the urban spatial structure, realizing balanced urban development, and improving the overall strength of the city. In the future, more social sensing data would be introduced to describe the interaction between residents and cities, like using point-of-interest data to refine the analysis unit into the building level.

#### ACKNOWLEDGEMENTS

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