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A space-time visualization analysis method for taxi operation in Beijing

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ABSTRACT

Traffic phenomena are associated with a complex dynamic behavior of spatiotemporal traffic patterns. It is possible to understand the features of real traffic by a spatiotemporal analysis approach for real measured traffic data. In this paper, a space-time visualization analysis method is designed and carried out for taxi spatiotemporal dataset from Beijing floating car data acquisition system and Beijing GIS data. Through this method, large-amount taxi GPS data is processed and the spatial–temporal trajectory is analyzed. And then taxi daily operation time, operating range and residence location of individual driver, vehicle operation and rest periods and other indicators are calculated, which are important characteristic parameters of Beijing Taxi Operations. In sum, continuous, comprehensive, and dynamic analysis information for monitoring taxi operation status can be acquired through the method. These information can provide the decision basis for city taxi operation management, and help to improve the city taxi operation management level.

1. Introduction

Transportation is a major application domain of geographic information system (GIS), frequently known as GIS-T (GIS for transportation). The developments in intelligent transportation systems (ITS) further increase the needs for handling dynamic disaggregate individual-based data for visualization and analysis, preferably integrated within a GIS environment [1]. While data acquisition is not a problem anymore, how to represent, analyze and visualize these large spatiotemporal data effectively presents major challenges to the research community. We have seen significant progress of implementing the time geography concepts in a GIS environment over the years [2]. These efforts have demonstrated that three-dimensional (3D) GIS provided a powerful platform to represent and analyze individual activities in a space-time context. So, in this paper, based on a large sample of GPS location data of taxi and GIS data of Beijing, a space-time visualization analysis method for Taxi Operation information is designed and carried out.

The paper is organized as follows: Section 2 briefly introduces research related to the development of GIS-T, space-time GIS and floating car system. In Section 3, the study area and the floating car data used in the paper are introduced. In Section 4, a 3D visualization platform for showing space-time path at individual level and managing temporal–spatial datasets is designed and developed based on ArcGIS Engine, and the method for data processing and identifying trip is elaborated. In Section 5, some

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findings and statistical results can be acquired based on the result of identifying trip. Finally, we conclude the paper with a discussion of our research.

2. Related research

2.1. Traffic spatiotemporal patterns

Traffic flow phenomena are associated with a complex dynamic behavior of spatiotemporal traffic patterns. The term spatiotemporal reflects the empirical evidence that traffic occurs in space and time. Therefore, only through a spatiotemporal analysis of real measured traffic data the understanding of features of real traffic is possible. In other words, spatiotemporal features of traffic can only be found, if traffic variables are measured in real traffic in space and time. The term a spatiotemporal traffic pattern (traffic pattern for short) is defined as follows:

- A spatiotemporal traffic pattern is a distribution of traffic flow variables in space and time. Examples of traffic variables are the flow rate q [vehicles/h], vehicle density ρ [vehicles/km], and vehicle speed v [km/h] or [m/s] (see, e.g., [3,4]).The term empirical features of a spatiotemporal traffic pattern means that the features are found based on an analysis of real measured traffic data.

2.2. Space-time path and visualization analysis

Although geographic information systems (GIS) have become increasingly capable of analyzing various spatial problems over the past few decades, additional functions of representing and analyzing both space and time dimensions for individual-based spatiotemporal datasets are needed. Then, large individual-based spatiotemporal datasets present challenges to researchers who attempt to comprehend the observed phenomenon and discover the hidden patterns and relationships in the dataset. A space-time GIS that can facilitate the exploration of spatio-temporal patterns, trends and relationships in a large and complex individual-based spatiotemporal dataset will be very useful to many application fields that have increasing access to such datasets [5,6]. Space-time path is a simple type of spatio-temporal features, as it portrays the location change history of a point object. A number of papers have focused on modeling moving objects [7,8]. Donggen developed a spatio-temporal data model that can represent the dynamic behavior of activity and to support activity-based modeling in a GIS environment [9]. In the model, the behavior of activities is represented as a sequence of two states—staying at and traveling between activity locations. The proposed model can support analysis and queries of activities from multiple perspectives, i.e. queries can be location-based, activity-based, time-based, and person-based. Hongbo Yu presented a GIS design that enables the representation and visualization of travel diary data (TDD) in a spatio-temporal framework. He demonstrated this spatio-temporal GIS design through an implementation that uses ArcGIS 8.3, ArcScene (ArcGIS 3D extension) [9]. Despite of these efforts, design of a spatio-temporal GIS data model for efficient and effective visualization and analysis of large individual-based spatio-temporal data remains an open research topic. All above research provide useful reference for our study.

2.3. Floating car data and its application

Floating car data acquisition system is a new traffic information collection system of road network. It is made of normal vehicles (such as taxis, buses, etc.) which are equipped with positioning and wireless communication apparatus, and communicate with the traffic information management center to achieve real-time data exchange. Because of the long operation time, wide coverage on roads, low cost in information collection, conveniently managed by center, city taxi become typical terminal vehicles of city floating car collection system at home and abroad [10,11]. On the one hand, it can provide important road conditions information for traffic management center. On the other hand, it has become important data source in analyzing the characteristics of city taxi operation. Nowadays there are many applications of floating car data [12,13], including providing the basis dynamic traffic information data of road network, detecting traffic events occurring on the road network, and predicting the travel time on road or expressway. Other researchers propose many useful ideas based on taxi. Veloso et al. [14] present a spatiotemporal analysis of taxis GPS traces collected in Lisbon, Portugal and discuss the taxi driving strategies and respective income. They also carry out the analysis of predictability of taxi trips for the next pick-up area type given history of taxi flow in time and space [15]. Zheng et al. [16] detect flawed urban planning using the GPS traces of taxis traveling in urban areas and find that pairs of regions with salient traffic problems and the linking structure as well as correlation among them. Zhang et al. [17] propose a method to discover anomalous driving patterns from taxi's GPS traces, targeting applications like automatically detecting taxi driving frauds or road network change in modern city. Li et al. [18] develop an improved ARIMA-based prediction method to forecast the spatiotemporal distribution of passengers in urban environment. Li et al. [19] present a trip analysis system which identifies the travel mode and purpose of the trips sensed by mobile devices and provides trip summaries and insights to mobile subscribers. One major application of taxi traces is discovering regions of different functions in city. Qi et al. [20,21] establish and confirm the relationship between the pick-up/drop-off characteristics of taxi passengers and the social function of city regions with qualitative and quantitative analysis. Yuan et al. [22] propose a framework that discovers regions of different functions in a city using both human mobility among regions and points of interests (POIs) located in a region. They segment an urban road network into regions by an image-processing-based approach [23]. In their work, a region is represented by a distribution of functions, and a function is featured by a distribution of mobility patterns [24]. Overall, the above study is only for GPS data analysis and testing indicators. The systematic data processing method