Research on Influencing Factors of On-Street Parking Based on Empirical Mode Decomposition

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Abstract. The change in the quantity of on-street parking needs more attention, and it changes with factors such as seasonality and holidays, by which both direct and indirect influence may be caused. Hence, in this paper, problems of how to analyze the quantity sequence of on-street parking through Empirical Mode Decomposition (EMD) are focused due to the quantity of on-street parking properties that can be labelled as nonlinearity and non-stationarity. By analyzing parking data in Xi’an, using EMD to decompose the quantity of on-street parking, analyze the influencing factors in each mode, and analyze the factors that affect on-street parking from a quantitative and qualitative perspective. Therefore, the effects of high frequencies (such as holidays) and low frequencies (such as seasonal) can be obtained. Our work will be reasonable for policymakers and business supervisors who wish to plan the on-street parking berths more reasonably.

Keywords. On-street parking; parking characteristics; EMD; parking forecasting.

1. Introduction

With the rapid expansion of the mobile industry chain and the acceleration of modern urbanization, the quantity and periodicity of use of urban motor vehicles have increased dramatically, which requires a certain parking space to meet the corresponding parking demand. At this stage, the space resources available for planning in cities are extremely limited. The supply of parking spaces is seriously insufficient. Therefore, under the dual constraints of insufficient parking supply and rising demand for parking, parking difficulties are becoming more and more serious in large and medium-sized cities. Insufficient parking spaces will increase the difficulty of finding parking spaces. Before the vehicles arrive at the parking site, car owners cannot grasp the usage of parking spaces and the development trend in the short term, causing more congestion on urban roads. At the same time, the parking space utilization rate of the site is low, resulting in a reduction in the economic benefits that can be generated. In this context, a series of parking difficulties caused by insufficient parking facilities and lack of effective parking guidance have become more serious. At present, as a social problem, parking difficulty has become a major problem faced by large and medium-sized cities, which has seriously hindered the development and progress of urban economic and transportation development.

From the perspective of roadside parking management, domestic scholars Pei, Yang and others analyzed the parking fees, parking regulations, and parking management methods that existed in parking management. They summarized the existing problems into three aspects and combined them with foreign experience. On-street parking management puts forward reasonable suggestions [1]. Through the analysis of the common problems of road parking management, Ma, Rong et al. summarized three modes and characteristics of road parking management, and compared their advantages and disadvantages, and finally put forward suggestions on road parking management [2].
Domestic Hao, Zhang, Ji and others analyzed the possibility of parking guidance system in intelligent traffic management from three aspects, and finally proposed that the application of parking guidance system in intelligent traffic management can greatly improve the existing traffic environment [3]. Li, Jiao, Du and others focused on the main functions of the intelligent parking system, and proposed the system architecture and the technical methods needed to realize the system. The research finally pointed out that the future urban intelligent parking management system can realize the full utilization and utilization of parking resources [4].

Foreign Bowman Cutter proposed Berth control standards. Through a survey of parking demand in some cities and towns in Los Angeles, it analyzed whether the growth of parking demand will significantly affect the demand for parking lots, and proposed Berth control standards for different land types and parking lots in different regions [5]. Prevos used the theoretical model of on-street parking facilities to summarize the calculation formulas of on-street parking capacity and occupancy rate in important locations [6]. Gheorghiu, Iordache, Cormos introduced a parking management system with automatic functions using sensors, actuators and displays. Experiments show that the use of this system makes parking more convenient and faster [7]. Meyer, McShane and others studied the impact of four parking strategies on the development of urban economy by controlling the overall level of parking supply, parking access, space distribution of parking supply, and price [8]. Chang, Hsu, Lin, et al. proposed a parking management solution based on the Internet of Things for on-street parking spaces. The implementation of this solution allows users to easily access the information of parking spaces near the user’s destination and design the best route at any time [9].

Domestic and foreign studies are lacking in the factors that affect the quantity of parking spaces on the roadside. Therefore, this article uses empirical model decomposition to reveal the inherent characteristics of the data sequence from the quantity of on-street parking, and contributes to street parking. This article's research on the factors affecting parking can provide a theoretical basis for subsequent research.

2. Introduction to Empirical Mode Decomposition (EMD)

2.1. Empirical Model Decomposition Concept

Empirical Mode Decomposition (EMD) is a method of signal processing decomposition jointly proposed by Huang in NASA and other scholars [10]. Different from the method of traditional time series decomposition, EMD will can conquer some of the original limitations. This method only decomposes the original signal based on the characteristics of the time scale of the data itself. Therefore, in terms of processing not linear and unstable signals, the EMD decomposition method is effective for the analysis and processing.

The analysis of time-frequency method based on Empirical Mode Decomposition (EMD) contains two different procedure. Firstly, use the EMD method to decompose the original time signal sequence, and decompose the original time sequence signal into multiple intrinsic mode functions (Intrinsic Mode Function referred to as IMF) at different frequencies. Secondly, by observing the characteristics of Hilbert transformation on each IMF, the respective momentary amplitude and the periodicity of momentary can be obtained. Next, explain the two concepts involved.

2.1.1. Instantaneous Frequency. The periodicity of momentary generally represents the change of the periodicity of the signal over time. In a general sense, periodicity represents a sine function or a cosine function with a steady-state varying amplitude over the entire data length range. Therefore, in order to express certain local characteristics of the signal clearly and conveniently, the basic concept of the periodicity of momentary is established. Since the periodicity of momentary is a function of time, that is, there is only one periodicity corresponding to each point in time, so it can only be used for expressing the signal characteristics of a single component. However, if you want to receive the signal of each single component of a multi-component combined signal, you need to use the Empirical Mode
Decomposition (EMD) method described in this chapter to decompose the signal of original. In the end, multiple single-component signals will be obtained, the so-called eigenmode function \[^{[11]}\].

2.1.2. Intrinsic Mode Function. The necessary condition for a certain the periodicity of momentary to be meaningful is that the function is symmetric, and its local average value is zero, with the same quantity of zeros and extreme points. Based on the decomposition of the composite signal into several single-component combinations, scholars Huang et al. proposed the idea of Empirical Mode Decomposition (EMD). The EMD is a process of gradually linearizing and smoothing nonlinear and unstable signals. By decomposing fluctuations on different time scales, the decomposed of trend component is acquired finally. From the perspective of the decomposition process, the characteristics of the data are retained; and these separated fluctuation components are called eigenmode functions. Intrinsic Mode Function (IMF) characterizes the fluctuation characteristics at different feature scales. After the original data sequence is decomposed to obtain different Intrinsic Mode Function (IMF) components, the final component is called the trend component, which is used for characterizing a certain long-term trend of the sequence in time.

For EMD, the extraction of IMF components is an important step. For the extraction of each Intrinsic Mode Function (IMF) component, there are generally two characteristics:

1. According to the range of variation based on the function's full time, the quantity of crossing zero points and the quantity of local extreme points should be the same or the difference between the two should be at most one.

2. From the perspective of the characteristics of local, at any time signal point, the average value of the upper and lower envelopes is 0, that is, the signal is locally symmetric on the axis of time.

2.2. The Algorithm Flow and Principle of Empirical Mode Decomposition (EMD). The composition of the original signal is mostly are multi-component signals in life, which basically do not meet the conditions of the Intrinsic Mode Function (IMF), and are difficult to analyze to a certain extent. At any time, the general signal contains more than one vibration mode, so that the general Hilbert transform cannot provide a comprehensive description of the periodicity content of the general signal. Therefore, Empirical Mode Decomposition (EMD) is to handle the complex original signal to acquire the single-component eigenmode function that is convenient for analysis. The Empirical Mode Decomposition (EMD) method has the following assumptions:

1. There are two extreme points in the original signal at least;

2. The characteristic time scale of the signal is decided by the time interval between adjacent extreme points;

3. If there is only an inflection point in the original signal, first differentiate it to obtain the extreme point in the signal, then decompose it, and finally integrate it to get the corresponding component.

In general, the basic concept of EMD decomposition can be considered as a process of screening. The specific implementation process is shown below:

① Find all extreme values of the original time series \( x(t) \).

② Using the function of cubic spline curve to fit all the extremum points found in ① respectively, and yield the upper envelope \( e_{\text{max}}(t) \) and the lower envelope \( e_{\text{min}}(t) \) finally.

③ Calculating the arithmetic average \( m_1(t) \) of the upper and lower envelopes at all times.

\[
  m_1(t) = \frac{e_{\text{max}}(t) + e_{\text{min}}(t)}{2}
\]

④ Remove the components of the average envelope from the original sequence \( x(t) \), and obtain a new time sequence of data after removing the low-periodicity signals:

\[
  h_1(t) = x(t) - m_1(t)
\]
⑤ Check $h_1(t)$ whether the conditions of the Intrinsic Mode Function (IMF) are corresponded: If the conditions are not met, start a new sequence and repeat the above steps until the Intrinsic Mode Function (IMF) conditions are met. Then define $c_1(t) = h_1(t)$, then $c_1(t)$ it is the first Intrinsic Mode Function (IMF) fluctuation component obtained from the decomposition of original sequence.

⑥ In the original sequence, we remove the Intrinsic Mode Function (IMF) component after the first decomposition, and the first difference signal sequence after removing the high-periodicity component can be obtained.

$$r_1(t) = x(t) - c_1(t)$$ (3)

⑦ The above obtained, re-use $r_1(t)$ as a new signal sequence, repeat the above steps to obtain the next Intrinsic Mode Function (IMF) component $c_2(t)$ and remaining $r_1(t)$ decomposed by the original time series.

⑧ Repeat the above steps n times, until the last remaining component $r_n(t)$ cannot continue to be decomposed. At this point, the components of the original sequence $c_i(t) (i=1, 2..., n)$ on different time scales and the residual items representing the trend $r_n(t)$ can be obtained.

The sequence of original could be finally expressed as:

$$x(t) = \sum_{i=1}^{N} d_i(t) + r_n(t)$$ (4)

According to the description of the steps, we can finally get the flow decomposition diagram of the EMD algorithm, as shown in figure 1 below.

![Figure 1. EMD decomposition algorithm flow chart.](image-url)
Among them, \( n \) is the quantity of Intrinsic Mode Function (IMF)s obtained after decomposition, \( r(t) \) is the sequence of residual item remaining at the end of the decomposition, and \( d_i(t) \) is the \( i \)th Intrinsic Mode Function (IMF) decomposed. The periodicity of the Intrinsic Mode Function (IMF) decomposed by the EMD method decreases step by step according to the order of the decomposition process, and each Intrinsic Mode Function (IMF) includes some change characteristics of the original sequence in terms of different time scales.

3. Numerical Experiments

3.1. Data Processing

The data in this essay is provided by the Parking Management Company of Xi’an, which includes the quantity of on-street parking in 2016. Use SAS software to process the data, get the daily parking quantity of all on-street parking spaces, a total of 365 days of parking data, part of data is shown in table 1. According to the data provided, it is found that there are missing data on some dates in October and November. Therefore, it is necessary to deal with the missing values.

| Date  | Number of parking | Date  | Number of parking | Date  | Number of parking | Date  | Number of parking |
|-------|-------------------|-------|-------------------|-------|-------------------|-------|-------------------|
| 01-01 | 47758             | 02-01 | 58950             | 10-01 | 52266             | 11-01 | 67069             |
| 01-02 | 49046             | 02-02 | 62563             | 10-02 | 47791             | 11-02 | 67856             |
| 01-03 | 49229             | 02-03 | 60851             | 10-03 | 46139             | 11-03 | 68281             |
| 01-04 | 57430             | 02-04 | 55559             | 10-04 | 47235             | 11-04 | 67853             |
| 01-05 | 58403             | 02-05 | 44832             | 10-05 | 39363             | 11-05 | 65456             |
| 01-06 | 59290             | 02-06 | 22984             | 10-06 | 48256             | 11-06 | 56165             |
| 01-25 | 59103             | 02-25 | 61825             | 10-25 | -                 | 11-25 | 67948             |
| 01-26 | 62426             | 02-26 | 62672             | 10-26 | -                 | 11-26 | 37295             |
| 01-27 | 64228             | 02-27 | 61153             | 10-27 | -                 | 11-27 | -                 |
| 01-28 | 64297             | 02-28 | 59311             | 10-28 | -                 | 11-28 | -                 |
| 01-29 | 65348             | 02-29 | 66055             | 10-29 | -                 | 11-29 | -                 |
| 01-30 | 58266             | 02-30 | 6-10              | 11-30 | -                 | 11-30 | -                 |
| 01-31 | 27386             | 02-31 | 10-31             | -     | -                 | -     | -                 |

For the processing of missing data, SPSS software is used for replacement processing. Combined with the characteristics of the actual missing data, the linear trend method at the point is used to replace the missing values. Import the data of the quantity of parking spaces obtained into the software of SPSS, use SPSS 20 software, and use the linear trend method at points to process and supplement the missing values. The processed data is shown in table 2.

After statistical analysis of roadside parking data in Xi’an, it can be seen that there are some problems with the current roadside parking service facilities in the city. The turnover rate is generally at a low level. Turnover rate is an important indicator used to measure the overall service efficiency of parking spots. The city’s average turnover rate is around 2.1, which is lower than the parking recommended by China in the “Guidelines for the Establishment of Parking Spaces on Urban Roads”. The effect of the differentiated charging policy for on-street parking spaces by location is not obvious. The setting of on-street parking spaces is irregular. The above analysis results indicate that the city's parking management has a lot of room for improvement.
Table 2. Data after missing value processing.

| Date  | Number of parking |
|-------|-------------------|
| 10-24 | 45330             |
| 10-25 | 47002             |
| 10-26 | 50347             |
| 10-27 | 52019             |
| 10-28 | 53691             |
| 10-29 | 57036             |
| 10-30 | 60380             |
| 10-31 | 63725             |
| 11-27 | 43607             |
| 11-28 | 49919             |
| 11-29 | 56230             |
| 11-30 | 62542             |

3.2. Matlab Programming to Realize EMD Decomposition

Use Matlab software to realize the EMD decomposition of the parking number through programming, and finally obtain 5 Intrinsic Mode Function (IMF) components and a residual item after the original sequence decomposition, as shown in figure 2. The ECG in the figure represents the sequence of original, imf1, imf2, imf3, imf4, and imf5 are five eigenmode functions decomposed from high periodicity to low periodicity. What’s more, res. is the residual. It can be shown as the figure that the fluctuation periodicity of each Intrinsic Mode Function (IMF) component is shrinking gradually, and the amplitude is expanding gradually.

Figure 2. Schematic diagram of each IMF component of the quantity of on-street parking.

The average period of each IMF component is shown in table 3. The average period is the ratio of the sample size to the quantity of maximum values of each IMF component [11].
According to the statistical results in table 3, the primary key of the average period from imf1 to imf5 is extended. Among them, the shortest average period is imf1, and about four days is a period. The longest average period is imf5, which is about six months. The average periods of imf2, imf3, and imf4 are two weeks, one month, and three months, respectively. Different averaging periods represent changes in different time scales.

Through the analysis of the impact of parking demand, the factors that affect the quantity of on-street parking are obtained. Through the analysis of the applicable scope of each parking demand forecasting model, the appropriate forecasting model is adopted, and the berth data of on-street parking is used to rationalize the demand prediction. The forecast results show that the demand for on-street parking spaces will increase significantly in the next few years. The demand for parking spaces in different parking areas and different parking activities has shown an increasing trend year by year. Therefore, the effective use of the stock will increase the increase Reasonable development has become an important measure to solve the increase in demand for roadside berths.

4. Conclusion
This paper summarizes the research results at home and abroad, combined with the current situation of on-street parking in a city, and analyzes the parking characteristics of on-street parking facilities from a quantitative and qualitative perspective through statistical analysis, and uses the method of Empirical Mode Decomposition (EMD) to analyze on-street parking. Decompose the quantity to obtain different eigenmode functions and residual items. By calculating the period of each modal function and analyzing it, the main factors affecting on-street parking under each eigenmode function are obtained, and the factors that affect the quantity of on-street parking are analyzed. Finally, reasonable approach for on-street parking are proposed.

This article analyzes the characteristics of roadside parking and puts forward the following suggestions. In terms of development increment, according to different parking activities and different parking lot areas, by analyzing the specific conditions of the area, selecting the appropriate road section area to set up roadside parking spots to meet the overall parking demand of the area. In terms of utilization of stock, a differentiated charging policy by time period is adopted, and parking time periods are appropriately adjusted to rationalize the distribution of parking demand. In addition, from the perspective of parking demand, efforts can be made to improve the service level of public transportation and attract people to change the way of public transportation to reduce parking demand. Adopt more advanced parking management equipment, improve corresponding laws and regulations, regulate the parking behavior of parkers from different perspectives, improve service efficiency, and better promote and guide the continuous development of roadside parking to the goal of order and standardization.

Although this article has carried out some research on the parking characteristics, parking demand prediction, parking space planning, etc. of a certain city, when using EMD empirical modal decomposition to decompose the quantity of on-street parking, the theory lacks a certain degree of parking analysis. Therefore, this article has not yet fully considered the influencing factors of each eigenmode function, and further discussion and research are needed in this regard.

| Table 3. Average period statistics of each component. | Average period (days) |
|------------------------------------------------------|-----------------------|
| IMF1                                                 | 4                     |
| IMF2                                                 | 13                    |
| IMF3                                                 | 33                    |
| IMF4                                                 | 73                    |
| IMF5                                                 | 183                   |
| Residual item                                         | 366                   |

7
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