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Dynamic analysis of traffic time series at different temporal scales: A complex networks approach

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HIGHLIGHTS

- We measure the complexity of traffic time series at different temporal scales.
- Complex networks are constructed by using the correlation coefficient among days.
- The proper critical threshold of networks is estimated by the derivative of density.
- Some statistical properties of complex networks are analyzed.
- We exploit the periodicity in traffic time series.

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ABSTRACT

The analysis of dynamics in traffic flow is an important step to achieve advanced traffic management and control in Intelligent Transportation System (ITS). Complexity and periodicity are definitely two fundamental properties in traffic dynamics. In this study, we first measure the complexity of traffic flow data by Lempel–Ziv algorithm at different temporal scales, and the data are collected from loop detectors on freeway. Second, to obtain more insight into the complexity and periodicity in traffic time series, we then construct complex networks from traffic time series by considering each day as a cycle and each cycle as a single node. The optimal threshold value of complex networks is estimated by the distribution of density and its derivative. In addition, the complex networks are subsequently analyzed in terms of some statistical properties, such as average path length, clustering coefficient, density, average degree and betweenness. Finally, take 2 min aggregation data as example, we use the correlation coefficient matrix, adjacent matrix and closeness to exploit the periodicity of weekdays and weekends in traffic flow data. The findings in this paper indicate that complex network is a practical tool for exploring dynamics in traffic time series.

1. Introduction

Traffic jams, accident and air pollution have attracted the attention from more and more people in the countries all over the world. Since the 1980s, developed countries have researched the technology of Intelligent Transportation Systems (ITS). Nowadays, the ITS has been definitely considered as the effective mean to solve the traffic problems. Advanced Traveler

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Information System (ATIS) is able to provide travelers with traffic information on road networks to guide their trip routes rightly. Advanced Traffic Signal Control System (ATSCS) applies optimal control strategies to improve traffic condition and relieve congestion. These performances depend on reliable and complete analysis for traffic time series, which includes two main parts: (1) accurate traffic flow prediction; (2) deep data mining and traffic flow modeling.

Recently, many scholars focus their interests on applying reliable models to accomplish high forecasting accuracy and produce a variety of achievements, especially in short term forecasting [1–5]. Yin et al. [1] used a fuzzy-neural approach to improve traffic flow predicting accuracy. Qi and Ishak [2] employed a stochastic approach to predict short-term traffic speed during peak periods on freeway in Orlando. Tigran et al. [3] introduced a real-time predicting mode based on spectral characteristics in traffic flow time series. Dunne and Ghosh [4] proposed a new multivariate short-term traffic flow prediction methodology in uncongested and congested regimes. Zheng et al. [5] introduced a neural network model combined with the theory of conditional probability and Bayes' rule, the combined model is demonstrated outperforms the singular predictors from the experimental test of Singapore's Ayer Rajah Expressway. Exploring the nonlinear dynamics and periodicity in traffic flow is another significant research field [6–11]. Liu et al. [6] developed a traffic flow model based on cell transmission by incorporating the frictional effect in managed lane (ML) systems. Gao et al. [7] established an improved traffic flow model by considering velocity-adaptation effect between neighboring vehicles, the simulation results showed the improvements of proposed model. Herrmann and Kerner [8] compared different modeling effect of traffic flow between microscopic and macroscopic models, and the results proved that the models had properties of the local cluster effect. Marasco [9] used a nonlinear hydrodynamic model of traffic flow to describe driver's behavior, the car density and flow evolution in tollgates. He et al. [10] used Recurrence Plot (RP) and the parameter of Recurrence Quantitative Analysis (RQA) to analyze the periodicity of traffic flow in an empirical study. Vlahogianni et al. [11] detected the nonlinearity and non-stationarity statistical properties in traffic flow time series by using the RP and the parameter of RQA. Dynamic analysis focuses on the microcosmic (space headway, time headway, speed, etc.) and macroscopic characteristics (density, occupancy, periodicity, etc.) of traffic flow. The aim of traffic flow forecasting is using the current and historical data to calculate the traffic flow state for next one or multiple steps in the future. Reasonable dynamic analysis of traffic flow is the basement of constructing a stable and effective prediction model. Therefore, full discover of dynamic characteristics can certainly improves traffic flow prediction accuracy.

By literature reviewing, we can see these predicting algorithms show desirable performance in certain applications and circumstances. However, with different model natures, this desirable performance is highly dependent on the data characteristics. Additionally, the basses of various traffic flow models are certain assumptions and their advantages are mainly demonstrated by ways of simulation. As traffic flow influenced by many complex factors, the prediction and traffic flow models are not able to describe the irregular, random and unsteady features in traffic systems completely, and the results of simulations can also not perfectly reflect the real condition of traffic systems. Thus, considering both the advantages and disadvantages of the foregoing traffic analyzing methods, one can reach the conclusion that a good method should appropriately describe actual state of traffic flow and analyze the nonlinear dynamics in traffic systems.

In the past few years, complex network has gained remarkable development in complex systems of various fields [12–23]. Recently, the theory of complex network has been introduced into the study of time series, which inspires the interests of researchers. By transforming time series into complex network, many scholars proposed various approaches to explore the dynamics in time series [24–31]. In these methods, how to create a proper complex network corresponding to time series is obviously one of the most significant issues. Dong [32] and Karimi [33] summarized three methods to construct complex network from time series: (1) Zhang et al. [34,35] proposed a new method to research the dynamics of ECG (Electrocardiogram) time series by using complex network. In this method, the optimal length of cycles in time series is first calculated. Then, each cycle is considered as node and relation between cycles treated as edges in complex network. (2) Lacasa et al. [36–38] introduced visibility algorithm to create complex network based on graph theory. A series of application using visibility graph to study the dynamics in time series show its potential advantages [39–43]. Wang et al. [43] studied macroeconomic series by the complex network approach and discovered the relationship between characteristics of complex network and statistical features of the original time series. These works indicate that converted complex network inherit some important features of the original time series. (3) Xu et al. [44] employed a method to map time series into complex network based on phase space reconstruction. In this method, two key issues attract concerns from different research fields: (1) algorithms for reconstructing phase space [45–47]; (2) methods for determining the critical threshold in complex network [27,28,48,49]. All these literatures suggest us that statistical features of complex network offer a new viewpoint and a helpful method to explore the dynamic characteristics in time series. With its different features from other time series, traffic flow time series have quasi-periodicity in long term and nonlinearity in short term. Complex networks are hence capable of supplying comprehensive statistical characteristics of the dynamics in traffic time series from a new angle.

Traffic flow time series have different features from the other time series for its quasi-periodicity and irregular fluctuation (monthly, daily, hourly variations). Current works about traffic flow prediction and analysis mainly focus on single time scale data. Results of traffic flow time series at multiple time scales are rarely published ([43] P.J. Shang et al., 2006; [4] Dunne and Ghosh, 2012). Through large time scale data, one usually can obtain long-term variation trends of time series. We can similarly obtain its local changes through small time scale data. For traffic flow time series, the travelers not only wish to understand the situation of traffic system during days or hours, but also they are interested in the volume of traffic flow