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SELF-AFFINITY OF VEHICLE DEMAND ON THE FERRY-BOAT SYSTEM

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The transportation problems are in evidence due to their importance. This type of problem is usually studied by nonlinear dynamics. In this paper, we study time series of vehicle demand by using the ferry-boat system between Salvador city and Itaparica island, in Bahia, Brazil. We observe an interesting behavior since these time series allow to observe genuine self-affinity effects. The scaling exponent α and the density of crossing points ρ are variables to describe long-range correlations (self-affinity) in time series of the vehicle demand. As the result we show α and ρ variation year by year.

Keywords: Self-affinity; vehicle demand; complex systems.

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1. Introduction

Transportation problems have attracted much attention in the fields of physics[1–5] and have been studied from a point of view of statistical mechanics and nonlinear dynamics.[6–11] Maritime transport is one of these problems, mainly in cities with a great expanse of water, for example, Salvador, Bahia (Brazil). Salvador sits on a vast bay which at 1100 square km, 70 km from north to south, and 60 km from east to west (at its widest point) is the largest in Brazil. What appears to be the other side of the bay as you look out over the water from Salvador, is actually the Itaparica island. There are several ways of getting there: the ferry-boat system, the catamaran, by small boat, etc.

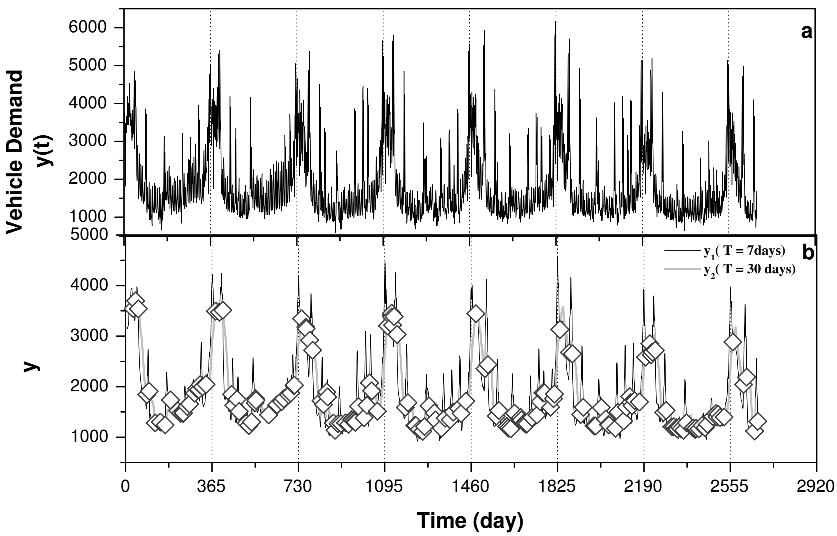

Fig. 1. (a) The original time series of vehicle demand by using the ferry-boat system, these data correspond to demand collected between Jan. 1, 1996 to Apr. 26, 2003 daily. (b) Two mobile averages, the black line is the mobile average y_1 for $T_1 = 7$ and the solid light gray line is the mobile average y_2 for $T_2 = 30$ days. The points $\diamondsuit$ are the crossing of the two mobile average. Vertical lines represent a one-year interval.

In this paper, we study the time series of vehicle demand between Salvador city and the Itaparica island by using the ferry-boat system.[12] This transport system has large economical importance and needs a lot of planning for its accomplishment. The Ferry-boat system transports vehicles and people from the continent to the island. A great number of tourists utilize the ferry-boats, mainly during the summer and weekends. This fact leads to a complex system with a strong seasonal effect and weather influence [Fig. 1(a)]. As a general rule, the daily demand during summer exceeds the daily demand during winter (seasonal component). These seasonal components can be smoothed out by statistical methods. We consider here two distinct methods, namely, the density of mobile averages[13] and the DFA.[14]

2. Results

Self-affine signals characterized by Hust exponent can be investigated through mobile averages. The density of crossing points between any two averages ρ is a measure of long-range power-law correlations in the time series. The application of this technique was first made by Vandewalle and Ausloos[13] using an artificial time series (midpoint displacement). From

$$\bar{y} \equiv \frac{1}{T} \sum_{i=0}^{T-1} y(t-i) \,, \tag{1}$$

that defines the average of y for the last T data points we can build a classical mobile average. Considering two mobile averages $\overline{y_1}$ and $\overline{y_2}$ that are characterized respectively over T_1 and T_2 such that $T_2 > T_1$. Our intention is to apply this technique in a real time series of vehicle demand by using the ferry-boat system. In Fig. 1(b) we show that the two mobile averages for the original time series [Fig. 1(a)]. The density of mobile averages is defined by $\rho = \diamondsuit/365$, in the case where $T_1 = 7$ and $T_2 = 30$ days.

We also analyze this problem using Detrended Fluctuation Analysis (DFA),[14] a method proposed to analyze long-range power-law correlations in nonstationary systems. One advantage of the DFA method is that it accounts for the long-range power-law correlations in signals with embedded polynomial trends that can mask the true correlations in the fluctuations of a noise signal. The range of systems that apparently display power law, hence self-invariant correlations, have increased dramatically in recent years, ranging from base pair in DNA and its evolution,[14,15] file editions in computer diskettes,[16] economics,[17,18] climate temperature behavior,[19,20] river flow and discharge,[21,22] cardiac dynamics,[23,24] light curves of astrophysical sources,[25,26] phase transition,[27] among others. The DFA method provides a relationship between $F(n)$ (root mean square fluctuation) and the box size n, characterized for a power-law $F(n) \propto n^{\alpha}$. In this way, α is the scaling exponent, a self-affinity parameter representing the long-range power-law correlation properties of the signal (fractal properties), such that if $\alpha = 0.50$ the signal is uncorrelated, if $\alpha < 0.50$ the correlation in the signal is antipersistent, and if $\alpha > 0.50$ the correlation in the signal is persistent.

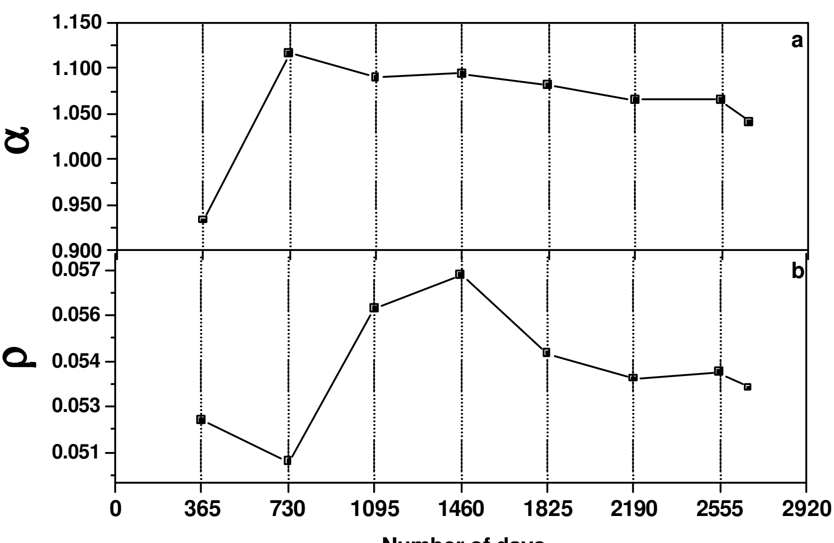

Fig. 2. Behavior of (a) the scaling exponent α (methodology based on the DFA analysis) and (b) the density of crossing two mobile averages ρ, year by year.

3. Discussion

We show the behavior of the α exponent in Fig. 2(a) (DFA method) and the density of crossing two mobile averages ρ [Fig. 2(b)], year by year. From this figure we can see that α and ρ show the same qualitative behavior, i.e., the values of these exponents are decreasing in the last years. From Fig. 1(a) we do not identify if the vehicle demand decreases (increases) with time. This is an interesting interval of analysis, because the daily demand decreases with time. Therefore, α and ρ can be very useful in the vehicle demand analysis. Finally, if this behavior continues for a long time the vehicle demand of the ferry-boat system tends to a more complex situation, like a random walk (uncorrelated time series).

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