Physica A 415 (2014) 31–42

Contents lists available at ScienceDirect

Physica A

journal homepage: www.elsevier.com/locate/physa

Dynamic features analysis for the large-scale logistics system warehouse-out operation

Can-Zhong Yao *, Ji-Nan Lin, Xiao-Feng Liu, Xu-Zhou Zheng

School of Economics and Commerce, South China University of Technology, Guangzhou, 510006, China

HIGHLIGHTS

- Warehouse-out time interval follows power-law with exponents close to 2.5.
- The warehouse-out mechanisms differ from that proposed by Barabasi and Vazquez.
- Warehouse-out behaviors of active individuals do not show any features of burst.
- Warehouse-out quantity follows Fractal Brownian motion with long-term correlation.
- Warehouse-out visibility graphs exhibit small-world and free-scale features.

ARTICLE INFO

Article history:
Received 3 February 2014
Received in revised form 4 July 2014
Available online 8 August 2014

Keywords:
Power-law distribution
Burst
Logistics system
Warehouse-out

ABSTRACT

In the paper, we research on the behavior dynamics for the large-scale logistics system warehouse-out operation systematically. First, we discover that steel products warehouse-out of different warehouses in a large-scale logistics system can be characterized by burst, and the warehouse-out inter-event time follows the power-law distribution with exponents close to $\alpha = 2.5$, which differs from the two classical models proposed by Barabasi (2005) and Vazquez (2005) respectively. By analyzing the warehouse-out inter-event time distribution of the products in one certain large-scale logistics system, we further discuss burst features and mechanisms of logistics system. Additionally, we find that in population behaviors, burst features can be explained by the priority that rooted in holidays and interior task scheduling. However, warehouse-out behaviors of active individuals do not show any features of burst.

Further, we find that warehouse-out quantity of steel products follows Fractal Brownian motion with the HURST exponent higher than 0.5 by means of R/S, which infers that the quantity of products in a logistics system is not only guided by prices in the present market, but also related closely to the previous quantity of warehouse-out. Based on V statistic, we compare memory length of different products in warehouses.

Finally, we apply complex networks visibility graphs for further validation of fractal features in a logistics system and find that almost every visibility graph exhibits small-world and scale-free features. Both R/S and complex networks visibility graphs reinforce that the warehouse-out quantity of products in a logistics system is not a random walk process, but contains intrinsic regularities and long-term correlation between present and previous warehouse-out quantity.

* Corresponding author. Tel.: +86 15813375525.
E-mail address: ycz20120911@gmail.com (C.-Z. Yao).

http://dx.doi.org/10.1016/j.physa.2014.07.077

0. Introduction

The Poisson process was widely used to quantify consequences of human activities, such as traffic flow patterns, accident frequencies, call center staffing, inventory control and blocked calls estimation. However, increasing empirical evidences indicate that no matter from patterns of communication, entertainment or work, time interval of human activities deviates from the Poisson prediction, and can be characterized by burst of rapidly occurring events separated by long periods of inactivity.

Correspondence patterns of Darwin and Einstein provide distinct evidences for the study of burst behaviors [1]. Over their lifetimes, Darwin sent at least 7591 letters and received near 6530, and Einstein sent more than 14,500 letters and received more than 16,200. Their correspondence exploded and fluctuated after their rise to fame. On average, Darwin wrote 0.59 letters per day while Einstein wrote 1.02 letters per day during the last 30 years of their lives, but these averages tend to cover up significant daily fluctuations. For example, Darwin wrote 12 letters on New Year's Day in 1874, and Einstein received 120 letters on 14 March 1949, his 70th birthday. According to the research, time interval, between the date when a letter was received and the date when the reply was sent, can be approximated with the power-law distribution. The best-fit power exponent of correspondence for Darwin is $\alpha = 1.45 \pm 0.10$ and for Einstein is $\alpha = 1.47 \pm 0.10$. In Hsue-Shen Tsien's and Lu Xun's letter records, time interval and relying data both reveal similar statistical properties of power-law distribution. Nowadays, regardless of advancement in communication patterns, behaviors of modern electronic communication still follow the power-scaling law and only power exponents vary.

Most of regularities in human dynamics, similar to the one found in the correspondence patterns of Darwin and Einstein, have certain universality. In 2005, Barabasi published the first paper in *Nature* about burst and heavy-tailed features of human dynamics and reveal the universal scaling law of human behaviors—*power-law behaviors*. The scaling law demonstrates that on time scaling, human behaviors are highly asymmetric. For wide and profound significance of the theory, it attracts attention of scientists from different fields, such as mathematics and system science.

Owing to advancement of information technology, the storage and process of big data could be realized, which provide foundation for the study of the time-scaling regularities of large-scale population behaviors. There are increasing evidences showing that time interval of human activities follows non-Poisson statistics regularities. For example, exchange of stocks [2], browsing the web [3], on-line movie sharing system [4] and library lending [5] have all been verified that time interval follows power-law distribution, whose power exponents are distributed in an interval ranging from 1 to 3.

Barabasi et al. [2] imply, with empirical studies and theoretical analyses, that systems driven by human actions have features that deviate from Poisson statistics: human behaviors can be characterized by short-time bursting and long-time inactivity. Discoveries above have challenged traditional queue models based on the Poisson process.

Another important aspect for behavior dynamics research is the intensity of behaviors. And for the logistics system, it refers to warehouse-out quantity. Traditional methods like ARIMA tend to output significantly accurate results in prediction, when they are applied to analyze time series with short-term memory. However, it is rather difficult in determining both a precise long-term period and a quasi-period by means of traditional methods in predicting fractal time series with long-term memory and heavy-tailed features. As numerous empirical studies are mentioned, non-Poisson statistics widely exist in the space and time distribution of human behaviors, and most of the behaviors could be characterized by Fractal Brownian motion. Therefore, studies on features of warehouse-out quantity time series with long-term memory have profound practical and realistic significance.

We take the Guangdong Yuzhu Logistics Base and three subordinate warehouses as the empirical objects, and also try to reveal basic features of warehouse-out quantity by analyzing time intervals. Furthermore, HURST exponent of warehouse-out behaviors, average memory length and fluctuation regularities of warehouse-out quantity are studied by using R/S, and features of Fractal Brownian motion in warehouse-out quantity are characterized and verified by complex networks visibility graphs. Our conclusion not only provides decision support for time scheduling and allocation management in logistics system, but also offers a strong case for studying the predictability in human behavior dynamics.

1. Features of burst and power-law distribution

Burst can be defined that an item happens frequently in a short period, and later it becomes inactive in a much longer period. Statistically, Burst could be characterized by heavy-tailed distributions and Power-law distributions. According to recent dynamics studies, distinctions between definitions of heavy-tailed distributions and Power-law distributions are not clear. Generally, distributions that deviate obviously from Poisson distributions and have long tails can be classified into different heavy-tailed distributions, which contain single distributions like Power-law distributions and mixed distributions such as stretched exponential distributions and q-exponential distributions.

According to empirical studies so far, Power-law distributions and their stretched forms commonly exist in human dynamics. In mathematics, if the density function of a random variable X is: $f(x) = C \cdot x^{-\beta}$, we usually consider X follows Power-law distributions. In reality, only few distributions can follow Power-law distribution in the entire value range and contain no peak values. In the situation of a positive power exponent, the possibility distribution tends to follow Power-law under condition of $x > x_{\min}$, therefore it would be reasonable to characterize the distribution as Power-law tail. The traditional least-squares fitting method has many limitations in fitting degree distribution in networks. Clauset