Physica A 441 (2016) 151–157

Contents lists available at ScienceDirect

Physica A

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

Human activity under high pressure: A case study on fluctuation scaling of air traffic controller's communication behaviors

Yanjun Wang [a,b,*], Qiqian Zhang [a,b], Chenping Zhu [c], Minghua Hu [a,b], Vu Duong [d]

[a] *College of Civil Aviation, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, PR China*
[b] *National Key Laboratory of Air Traffic Flow Management, Nanjing 210016, PR China*
[c] *College of Science, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, PR China*
[d] *John von Neumann Institute - Vietnam National University, Ho Chi Minh City, Viet Nam*

HIGHLIGHTS

- We perform fluctuation scaling analysis of air traffic controllers' communications.
- One real operational dataset and one real-time training dataset were investigated.
- We found controller's communications behavior follows Taylor's power law.
- The scaling exponent found in operational data is larger than that in training data.
- Human dynamics under pressure is more likely dominated by the exogenous force.

ARTICLE INFO

Article history:
Received 25 August 2014
Received in revised form 26 May 2015
Available online 8 September 2015

Keywords:
Fluctuation scaling
Air traffic control
Taylor's law
Human dynamics

ABSTRACT

Recent human dynamics research has unmasked astonishing statistical characteristics such as scaling behaviors in human daily activities. However, less is known about the general mechanism that governs the task-specific activities. In particular, whether scaling law exists in human activities under high pressure remains an open question. In air traffic management system, safety is the most important factor to be concerned by air traffic controllers who always work under high pressure, which provides a unique platform to study human activity. Here we extend fluctuation scaling method to study air traffic controller's communication activity by investigating two empirical communication datasets. Taken the number of controlled flights as the size-like parameter, we show that the relationships between the average communication activity and its standard deviation in both datasets can be well described by Taylor's power law, with scaling exponent $\alpha \approx 0.77 \pm 0.01$ for the real operational data and $\alpha \approx 0.54 \pm 0.01$ for the real-time training data. The difference between the exponents suggests that human dynamics under pressure is more likely dominated by the exogenous force. Our findings may lead to further understanding of human behavior.

* Corresponding author at: College of Civil Aviation, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, PR China.
E-mail addresses: ywang@nuaa.edu.cn (Y. Wang), zhangqq@nuaa.edu.cn (Q. Zhang), oldpigman1234@126.com (C. Zhu), minghuahu@nuaa.edu.cn (M. Hu), vu.duong@jvn.edu.vn (V. Duong).

http://dx.doi.org/10.1016/j.physa.2015.08.040

1. Introduction

Scaling behavior is thought to be one of the hallmarks of a complex system, indicating that no characteristic scale dominates the dynamics of underlying process. In the past few decades, considerable work has been contributed to the study of scaling behaviors emerged from various fields, ranging from biology, through economic systems to human social activities [1–5]. Human as the most complex one exhibits this astonishing phenomena at different scales as well, deep down from cell activities and DNA behavior, up to social activities. Given the importance of human activities, research from biology, cognitive science, and brain science has long sought to explain the underlying mechanisms from different perspectives [6]. Recently, there is a surge of reports on human dynamics which have uncovered regular patterns of human communications and other interactive activities, patterns that are characterized with heavy-tailed, power-law distributions instead of ever-belief Poisson-like random distributions [7–15]. Several kinds of mechanisms have been suggested to explain the mechanisms which govern human activities, including priority based queuing processes when human execute tasks [7], interests driven human behavior [16], cascading non-homogeneous Poisson process with circadian cycle [10], and the combination of Poisson processes and decision-based queuing processes [13]. Quantitative assessments from the circulations of bank notes and investigations on mobile phone datasets have found that the human trajectories in daily activities show a high degree of temporal and spatial regularity. Models based on Lévy flights and Random Walk have been developed to explain the mechanisms which can lead to the scaling law of human trajectories [17–21].

It should be noted that all the above examined data are got from deliberate human activities. Unfortunately, there are few evidences from a task-specific activity, for instance, the logistics operation [22], to support the universal mechanisms governing the instinct nature of human activities. Particularly, human operators in the safety-crucial complex systems, such as air traffic controllers, usually work under heavy pressure, and they are requested to give correct responses promptly to any change of system states. In contrast to the routinized behaviors, they are clearly aware of the purposes of their actions since any error or failure may result in the loss of life or property. Data limitations used to hinder the efforts to systematically analyze their activities across a wide range of fields. In air traffic management system, however, we are able to record air traffic controller's communication activities. Statistical physics has been applied to air traffic control field to understand the underlying dynamics of the system [23–25]. Previous study has shown that air traffic controller's communication activities do exhibit heavy-tailed feature, with inter-communication times characterized by inverse Gaussian distributions [26]. Due to the heterogeneous working environments, the universal mechanism of air traffic controller remains unknown.

To further investigate controller's behavior, we turn to the method of fluctuation scaling. Human, like many dynamical systems, is subject to stochastic perturbations, therefore exhibits fluctuations. It is believed that fluctuations reflect functional states of the system, providing important clues to the underlying dynamics. Complex fluctuation scaling phenomena have been observed in many systems, ranging from ecology [27–31], river flow [32], through human gait [33,34], electroencephalogram [35], and musical rhythms [36,37] to financial markets [38–42], urban transportation systems [43–45], and social activities [4,46]. Taylor's power law has been applied successfully to various complex systems to characterize the relationship between the fluctuations in the activity of an element and the average of the activity [27]. The relationship can be described as

$$\textit{fluctuation} \approx \langle \textit{average activities} \rangle^{\alpha}.$$

The origin of fluctuation scaling is becoming increasingly of interest to the statistical physicists [47–49]. Our primary interest here is to investigate the adaptive behavior of controllers through the study of the fluctuations of their communications. In this paper, we performed the standard ensemble fluctuation scaling analysis on two empirical datasets by defining the number of controlled aircraft as the size-like parameter. Analytical results show that air traffic controllers' communication activity do exhibit fluctuation scaling phenomena. We found that the scaling exponent in the real operational dataset is larger than that in the simulation dataset, which suggests that human activity under pressure is more likely to be dominated by the exogenous factors. Our findings may lead to further understanding of human behavior.

2. Background on air traffic control and fluctuation scaling

2.1. Air traffic control and controller's communication activities

Air traffic control is the service provided by the air traffic controllers who are responsible for expediting and maintaining a safe and orderly flow of aircraft traffic. To keep the traffic manageable, the controlled airspace/airport is subdivided into sectors with one or two controllers managing the flights inside. Cognitive analyses have demonstrated that controllers are required to complete many tasks in response to the rapidly changing of air traffic, many of which must be time-shared and communication related with high pressure [50].

Controllers direct aircraft moving on the ground and in the air by delivering the instructions and clearances to the pilots through a unique frequency between them. Communication between pilots and controllers must be in a clear and unambiguous way in order to ensure the safety and efficiency of air traffic. To maximally utilize the capacity of communication channel while to reduce the risk of misunderstanding, controllers and pilots use standardized phraseology during air–ground communication [51]. In general, the grammar structure of transmission is determinate, and the vocabulary is limited. The speech rate should be adjusted to allow clearances etc., to be written down if necessary.