Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 23 (2017) 157–173

Transportation Research Procedia

www.elsevier.com/locate/procedia

22nd International Symposium on Transportation and Traffic Theory

Experimental and Empirical Investigations of Traffic Flow Instability

Rui Jiang[1,2,*], Cheng-Jie Jin[3], H.M.Zhang[4,5], Yong-Xian Huang[2], Jun-Fang Tian[6], Wei Wang[3], Mao-Bin Hu[2], Hao Wang[3], Bin Jia[1]

[1]*MOE Key Lab. for Urban Transp. Complex Systems Theory & Technology, Beijing Jiaotong Univ., Beijing 100044, People's Republic of China*
[2]*School of Engineering Science, University of Science & Technology of China, Hefei, Anhui 230026, People's Republic of China*
[3]*Jiangsu Key Laboratory of Urban ITS, Southeast University of China, Nanjing, Jiangsu 210096, People's Republic of China*
[4]*Department of Traffic Engineering, School of Transportation Engineering, Tongji University, Shanghai 200092, People's Republic of China*
[5]*Department of Civil & Env. Engineering, University of California, Davis, USA*
[6]*Institute of Systems Engineering, College of Management & Economics, Tianjin University, Tianjin 300072, China*

Abstract

Traffic instability is an important but undesirable feature of traffic flow. This paper reports our experimental and empirical studies on traffic flow instability. We have carried out a large scale experiment to study the car-following behavior in a 51-car-platoon. The experiment has reproduced the phenomena and confirmed the findings in our previous 25-car-platoon experiment, i.e., standard deviation of vehicle speeds increases in a concave way along the platoon. Based on our experimental results, we argue that traffic speed rather than vehicle spacing (or density) might be a better indicator of traffic instability, because vehicles can have different spacing under the same speed. For these drivers, there exists a critical speed between 30 km/h and 40 km/h, above which the standard deviation of car velocity is almost saturated (flat) along the 51-car-platoon, indicating that the traffic flow is likely to be stable. In contrast, below this critical speed, traffic flow is unstable and can lead to the formation of traffic jams. Traffic data from the Nanjing Airport Highway support the experimental observation of existence of a critical speed. Based on these findings, we propose an alternative mechanism of traffic instability: the competition between stochastic factors and the so-called speed adaptation effect, which can better explain the concave growth of speed standard deviation in traffic flow.

Peer review under responsibility of the scientific committee of the 22nd International Symposium on Transportation and Traffic Theory.

Keywords: Traffic flow stability, Car-following, Experiment

* Corresponding author. Tel.:+0086-10-5168-7375; fax: +0086-10-5168-4240
Email address: jiangrui@bjtu.edu.cn, yitaikongtiao@163.com, hmzhang@ucdavis.edu

Peer review under responsibility of the scientific committee of the 22nd International Symposium on Transportation and Traffic Theory.
10.1016/j.trpro.2017.05.010

1. Introduction

Many studies have been performed to examine traffic conditions of uninterrupted flow (see e.g., review papers and books, Chowdhury et al., 2000; Gazis, 2002; Helbing, 2001; Kerner, 2004, 2009, 2013; Nagel et al., 2003; Saifuzzaman and Zheng, 2014; Wilson and Ward, 2011). The empirical studies have revealed many interesting and important features of traffic flow, including traffic oscillations, traffic instability, traffic breakdown, capacity drop, wide scattering of congested traffic data and so on (see e.g., Banks, 1991;Bertini and Monica, 2005; Cassidy and Bertini 1999; Kerner and Rehborn, 1996, 1997; Kerner, 1998; Knoop et al., 2008; Mauch and Cassidy, 2002; Persaud and Hurdle, 1991; Schönhof and Helbing, 2007, 2009; Treiber et al., 2010; Treiterer and Myers, 1974; Windover and Cassidy, 2001).

Instability is an important feature of traffic flow. When traffic flow is unstable, small disturbances grow in a traffic stream and can finally lead to traffic jams, which are sometimes called phantom jams (Treiterer and Myers, 1974; Gazis and Herman, 1992). This is undesirable and the stop-and-go movements that the instability produces not only are a nuisance to motorists, but also consume more fuel, and likely cause more accidents. Therefore, studies on traffic instability have attracted wide interest of traffic flow researchers (see e.g., Li et al., 2010, 2012, 2014; Zheng et al., 2011a, 2011b; Mauch and Cassidy, 2002; Kim and Zhang, 2008; Yeo and Skabardonis, 2009; Zhang and Kim, 2005; Chen et al., 2012a, 2012b; Laval and Leclercq, 2010; Laval et al., 2014). It is highly desirable to understand the mechanism of traffic instability and be able to eliminate it through modifications of driving behavior or traffic control.

Many vehicular traffic models proposed in the literature, such as the General-Motors family of car-following models (Chandler et al., 1958; Gazis et al., 1959, 1961), the Gipps model (Gipps, 1981), the optimal velocity model (Bando et al., 1995), the intelligent driver model (Treiber et al., 2000), and so on can be unstable in certain ranges of traffic conditions (namely spacing between cars). Such models have unique speed-spacing relations under steady state conditions and are termed as two-phase models by Kerner (2009, 2013) because the resulting fundamental diagram (flow-density diagram) has a free-flow (phase 1) and a congested (phase 2) branch. The basic instability mechanism in these models is due to the nonlinear instability of the steady state, or in other words, traffic becomes unstable when drivers' reaction times are longer than their anticipation times of disturbance waves reaching them (e.g., Holland 1998). On the other hand, Kerner (2004, 2009, 2013) claimed, based on empirical observations, that congested flow can be further classified into synchronized flow and wide moving jams and proposed a three-phase traffic flow theory. In this theory, Kerner stipulates that the steady state of synchronized flow occupies a two-dimensional region in the flow-density plane, rather than a unique relationship between flow and density. Kerner further argued that traffic instability from free flow to synchronized flow (also called traffic breakdown) is caused by discontinuities in driver behavior (a discontinuity in driver's over-acceleration probability) rather than inadequate reaction times.

Now we revisit traffic stability in car-following. We consider a platoon of cars is stable even if the disturbances grow in the platoon but eventually cap off without causing cars to come to a complete stop. If the growing disturbances eventually cause cars to make a complete stop, the platoon is considered not stable. Recently, we have reported an experimental study of car following in a 25-car-platoon on an open road section (Jiang et al., 2014, 2015; Jin et al., 2015). It has been found that the spacing between a leading car and a following car can change significantly even though the speeds of the two cars are essentially constant and the velocity difference is very small. The length of the platoon can differ sizably even if the average velocity of the platoon is essentially the same. The standard deviation of the velocity of each car increases along the platoon in a concave or linear way*. Traffic states inside hyper congestion are not homogeneous, cars in the rear part of the 25-car-platoon will move in a stop-and-go pattern. These features clearly contradict the fundamental assumption that there is a unique relationship between vehicle speed and its spacing in traditional car-following models.

The trajectory data such as NGSIM contain many confounding factors, which makes it difficult to isolate the dynamical behavior of car-following from those of lane-changing and other interactions. For example, it is still not

---

[*] We would like to mention that the concave growth pattern of oscillations has also been observed in NGSIM data, see Tian et al. (2016).