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Driver perception uncertainty in perceived relative speed and reaction time in car following – A quantum optical flow perspective

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ABSTRACT

Driver perception uncertainty characterized in perceived relatnd reaction time plays a key role in influencing car-following behavior; and however, is rarely investigated in related literature. Grounded on quantum optical flow theory, we propose a dynamic and stochastic driver perception model to investigate the relationship between the uncertainty of perceived relative speed and that of reaction time during car following. Specifically, the proposed model hypothesizes that driver perceived speed and reaction time are time-varying and uncertain, and correlate in a trade-off relationship mimicking the form of Heisenberg Uncertainty Principle. To test the assertion that a trade-off relationship of uncertainty in perceived relative speed and reaction time exists in car following, this study conducts qualitative analysis followed by a two-stage experiment rooted in quantum optical flow theory using data collected from a driver simulator. Analytical results further elucidate car-following phenomena under driver-perception uncertainty, potentially facilitating the development of new traffic flow theories.

1. Introduction

Driver perception uncertainty exists ubiquitously, and plays a key role in characterizing driver car-following behavior and induced other lane traffic phenomena. Lane traffic phenomena refer to intra-lane and inter-lane traffic phenomena, including car-following, lane-changing, and vehicular queuing. In fact, driving is both visual and psychological complex. Roughly 90% of driving information is input through the eyes (Robinson et al., 1972). Unfortunately, no one in driving can perfectly perceive all the driving information with 100% accuracy, according to the quantum optical flow theory (Baker, 1999; Sheu, 2008). Particularly, perception errors may occur while perceiving moving images in driving due to the wave-image duality during the transfer of visual information (Baker, 1999), thus resulting in the uncertainty of driver perception in car following (Sheu, 2013) which complicates lane traffic phenomena. Furthermore, lane traffic phenomena characterized by the interactions and reactions of drivers of multiple vehicles surrounding are rooted in psychological reactions of the drivers (Papageorgiou and Maimaris, 2012). For example, congestion upstream of a traffic bottleneck or shockwave can vary in propagation length, depending upon the upstream traffic flow and density perceived by drivers (Shiomi et al., 2011). Therein, shockwaves were also discussed in numerous previous studies (Bose and Ioannou, 2000; Nagai et al., 2006; Tanaka et al.,

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2006;Hanaura et al., 2007; Chiu et al., 2010). From either a theoretical or practical perspective, modeling lane traffic phenomena grounded upon such an unrealistic assumption of traffic parameter determinism may no longer be valid in the context of driver perception uncertainty. Instead, it is arguably agreed that driver perception uncertainty which underlies driver behavioral uncertainty should be taken into account in characterizing lane traffic phenomena.

Car-following is one of lane traffic phenomena. The car-following means that a vehicle follows its leading vehicle by maintaining appropriate space and time gaps on a roadway. As to the issue of driver perception uncertainties in car following, relative speed (RS) and reaction time (RT) are two crucial factors. In reality, a new branch of car-following research has been focused on the psycho-physical aspects (Wiedemann, 1974; Leutzbach, 1988; Toledo, 2003), particularly with respect to RS (Hoffmann and Mortimer, 1996; Jiang et al., 2002; Shiomi et al., 2011) and RT (Mehmood and Easa, 2009; Sheu and Wu, 2011; Koutsopoulos and Farah, 2012; Wagner, 2012; Sheu, 2013). For example, the work of Sheu (2008) which used the quantum-optical-flow-based model to explain driver stimulus and response was one of the pioneering researches in the association of uncertainty in perceived relative speed (PRS) with driver behavior in car following. Specifically, Sheu asserted that as backward PRS increases, the resulting psychophysical momentum (PPM) and psychophysical energy (PPE) increase. Therein, the uncertainty of PRS in car following is defined as the standard deviation of PRS, where PRS refers to as the relative speed between the leading vehicle (LV) and following vehicle (FV) perceived by the FV driver. Using a quantum-mechanics-based approach, Sheu (2013) further developed a dynamic stimulus–response car-following model which consists of the following two recursive phases: (1) transformation of visual stimuli, and (2) approximation of speed adjustment. Nevertheless, the uncertainty in reaction time and its association with other perception uncertainties remain as critical issues which are not addressed in Sheu's works (2008, 2013). For example, as argued in Sheu (2013) the uncertainty in RT may contribute to irregular start-up delays during a forward shockwave (*i.e.*, when vehicular queuing starts to disperse), thus leading to greater deviations in reproducing vehicular trajectories, compared with normal car-following cases. Moreover, the association of the uncertainty in RT with that in PRS may exist, collectively influencing quantum optical field and driver behavior; and however, remains unclear in characterizing car-following behavior.

Despite the importance of the driver perception uncertainty characterized in PRS and RT when analyzing or predicting driver response during car following, it does not seem to draw much attention in the existing car-following models, including General Motors (GM) models (Koutsopoulos and Farah, 2012) and psycho-physical models (Toledo, 2003). Instead, most car-following models emphasize vehicular spatial/temporal characteristics, *e.g.*, relative speed, spacing, and headway, which are assumed to follow the laws of pure physics and mechanical engineering, where the uncertainties in human psychological factors, and their interactions jointly influencing drivers can be ignored.

Theoretically, human psychological factors, such as driver perception of moving environments and stimulated responses should be embedded in a driver behavior model to characterize "real" driver behavior (Paz and Peeta, 2009; Chen et al., 2014). Particularly, this work aims at the effect of joint uncertainty of PRS and RT on car-following behavior, and thus, argues that the following four related subjects should be well clarified before modeling car-following behavior.

First, this work is theoretically grounded on quantum mechanics in optical flow which has been investigated in some pioneering researches (Gibson and Crooks, 1938; Gibson, 1950, 1966; Lee, 1980; Baker, 1999; Sheu, 2008, 2013).

Second, in terms of psychophysical factors related to perceived stimuli, Baker (1999) discussed the quantum mechanics of the optic flow and its application to driving in uncertain environments. Some forms of the Heisenberg Uncertainty Principle were considered when the uncertainty in the position of focal point and that in PPM follow a trade-off relationship at best equal to a time-based action constant h. Furthermore, to address the psychological values of psychophysics Sheu (2008) investigated variations in psychophysical factors under anomalous traffic environments such as lane-blocking incidents. The influence of these factors on driver behavior may contribute to the fact that existing car-following models fall short when deducing resulting lane traffic phenomena. Sheu also extended a study using a quantum optic flow-based driver's stimulus–response model to characterize car-following behavior (Sheu, 2013).

Third, RT can be deemed as a psychophysical factor. That is, RT is the time between the moment sensory stimulus appears and the consequent behavioral response. Mehmood and Easa (2009) asserted that RT exists when the front vehicle brakes and its brake light is on, and deceleration RT starts when the FV driver reacts and changes his/her speed. They also obtained experimental results indicating that RT differed significantly in normal, urgent, and stationary scenarios. Both urgency and expectancy significantly affect RT. Some empirical studies (Lee, 1976; Wang et al., 2011) indicated that braking RT is roughly 1s for an alert driver.

Fourth, previous research has shown that the two principal factors accounting for the majority of rear-end collisions are a driver's inability to perceive and/or react to the actions of the LV and following an LV too closely (Knipling et al., 1993). Whenever uncertainty about when the LV's brake lights will come on increases, RT increases (Fitts and Posner, 1967). Additionally Wang et al. (2011) developed a safety-based behavioral approaching model with different driving characteristics.

In summary, although a few studies have identified the psychological factors related to perceived stimuli to characterize traffic behavior under quantum uncertainties, no dynamic visual model identifies the unpredictability that limits and informs human behavior.

Understanding the relationship of uncertainty in PRS with that in RT can provide additional insights regarding the correlation between driver perception and behavior under uncertainties, such that one can rationalize the dynamics of driver behavior in car-following scenarios. Notably, this work defines RT as the elapsed time ($T \equiv t_2 - t_1$) from the time when the