International Journal of Transportation Science and Technology 5 (2016) 227–238

Contents lists available at ScienceDirect

International Journal of Transportation Science and Technology

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

Modeling cooperation and powered-two wheelers short-term strategic decisions during overtaking in urban arterials

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ARTICLE INFO

Article history:
Received 2 September 2016
Received in revised form 26 November 2016
Accepted 28 November 2016
Available online 28 December 2016

Keywords:
Powered two-wheelers
Overtaking
Urban arterials
Game theory
Structural equation modeling

ABSTRACT

A difference between Powered Two Wheelers (PTW) drivers' behavior and other drivers' behavior in urban arterials is the frequency of overtaking. The present paper focuses on PTW overtaking and models the specific behavior using concepts of Game Theory. Both the PTW driver and the lead vehicle's driver are assumed rational decision-makers that develop strategies, trying to maximize their payoffs. These strategies may be cooperative or not with respect to the distances and safety gaps and other behavioral aspects. The payoff function is formulated based on a novel latent statistically determined driving indicator, which quantifies both the driving risk and comfort. The proposed model is evaluated using trajectory data from video recordings on an urban arterial. Results show that both drivers have maximized gains by following a cooperative strategy. Findings also reveal that the successful overtaking rate is higher, when the PTW driver is non-cooperative, whereas lower overtaking rates occur, when the driver of the lead vehicle is non-cooperative. Finally, the concepts of Dominant Strategies, bounded rationality and the construction of the optimum payoff function are further discussed.

1. Introduction

One of the players that got vigorously into the game of city commuting is Power-Two Wheelers (PTW). PTW can take advantage of their smaller width and horse power to weight ratio to navigate through city traffic more efficiently through overtaking, filtering, or lane sharing (Barmpounakis et al., 2016a; Correa et al., 2016; Wong and Lee, 2015). Moreover, with the increasing popularity of PTW in European roads, their effect on multimodal urban environments has been magnified (ACEM, 2015). The interactions with the rest of the vehicles on urban road networks may be significant to traffic operations and safety, and may lead to increased delays at intersections, reduced level of service at arterials and increased accident risk for both PTW drivers and other road users (Barmpounakis et al., 2016b). Therefore, the manner PTW interact with the rest of the traffic could underlie a key issue of traffic operations management.

Most studies model PTW macroscopic and microscopic traffic characteristics during normal conditions or attempt to address safety issues using macroscopic or individual based Intelligent Transportation Systems (ITS) applications (Barmpounakis et al., 2016b; Vlahogianni et al., 2012). Literature has emphasized on the need to address special cases of traffic flow conditions with emphasis on overtaking phenomena that, until recently, have been rarely addressed in the context of

Peer review under responsibility of Tongji University and Tongji University Press.

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http://dx.doi.org/10.1016/j.ijtst.2016.11.001
2046-0430/

urban road networks, as well as PTW circulation (Lee et al., 2012; Vlahogianni et al., 2013, 2012). Most of these studies suggest that there is a strong interaction between PTW and surrounding vehicles, affecting how they move, which is still an ongoing research topic, characterized by complex traffic phenomena and trajectories (Barmpounakis et al., 2016a; Mallikarjuna and Kuzhiyamkunnath, 2014; Minh et al., 2005; Nguyen and Hanaoka, 2013; Theofilatos and Yannis, 2015; Wong and Lee, 2015).

The principles of Game Theory can be implemented in overtaking conditions, since both PTW and the rest of the road users (drivers, pedestrians etc.) are continuously challenged to make decisions in order to move fast and safely on urban arterials. Given that drivers of different means of transportation have specific characteristics and different way of moving than others, the study of how they make decisions of conflict and cooperation should be studied under the prism of driving behavior. Thus, a PTW driver and the driver of the vehicle being overtaken are considered two different rational decision makers (players), both developing strategies trying to get the best outcome for their decisions. Each one has his own set of actions depending on his driver profile.

This game theoretic concept is distinctive to drivers following specific driving patterns while overtaking. It is assumed that each driver has his own strategy when commuting, affecting the surrounding vehicles and traffic macroscopically, for example when it comes to special maneuvers, this strategic thinking can have a considerable effect on traffic flow and traffic volume, by changing the placement of the vehicles, density or distance and time headway between them. Therefore, the study and modeling of drivers' strategies can be the square one for designing systems that would not only optimize traffic flow but also enhance safety in an automated or semi-automated vehicles environment. Especially for the future roadway conditions and Vehicle to Vehicle (V2V) environments, understanding and controlling the strategies of the drivers is of crucial importance for designing efficient communication protocols.

The aim of this paper is to present a game theoretic approach to describe PTW overtaking phenomena and interactions with the rest of the traffic to set the framework of a Cooperative ITS design. First, a concise theoretical analysis on Game Theory and its solution concepts are presented in the context of traffic overtaking conditions. Next, a definition of cooperativeness among drivers is provided and the specifications of a novel payoff function are extracted using multivariate structural equation statistical modeling. Following, the study area and the driving experiment are described, and the payoffs for each player are estimated based on real data extracted from video recordings. The Game Theoretic overtaking model is, then, formed and evaluated. Finally, conclusions are summarized and future research directions are discussed.

2. Game theory: a short introduction

Game Theory includes mathematical tools and models for describing conflict and cooperation conditions between intelligent rational decision makers that will affect their welfare (Myerson, 2013). In transportation and traffic engineering, game theory applications refer mostly to logistics, urban networks and public transportation, mostly connected with economics (Hollander and Prashker, 2006; Zhang et al., 2010).

Concepts of Game theory have been previously applied to traffic analysis and modeling with the aim to explain driving patterns and behavioral characteristics, for example the merging or lane changing maneuvers (Kita, 1999; Kita et al., 2002; Liu et al., 2007; Talebpour et al., 2015), the decrease in safety due to the selfish actions of drivers (Rass et al., 2008), or the formulation of control strategies for automated vehicles, while obeying safety and comfort requirements (Wang et al., 2015). In most of the above studies, the use of strategic decision making of explaining drivers behavior has acknowledged. Nevertheless, game theory applicability to driving behavior has been rarely supported by real world data. Towards this direction, in a recent study, a strategic game was formed to explain the PTW overtaking procedure in urban arterials, in which each player considers his plan of actions at the beginning of the game without evaluating the other player's action (Barmpounakis et al., 2015).

This study extends previous research and proposes an extensive-form game to model PTW overtaking behavior, which is an explicit description of sequential structure of the decision problems encountered by the players in a strategic situation, where a player can consider his plan of actions at any point of time at which he has to make a decision (Osborne and Rubinstein, 1994). As overtaking phenomena are common in everyday commuting, it is assumed that both players know the strategy that the other player has chosen. Therefore, the game formed is an extensive game with perfect information.

A finite extensive game consists of a finite set of $i = 1, 2, \ldots, I$ players and a set X of decision points (nodes), which forms a tree, with $Z \subset X$ being the terminal nodes. Moreover, a set of functions that describe for each $x \notin Z$, the player $i(x)$ who moves at x, the set of $A(x)$ of possible actions at x and the successor node$n(x, a)$ resulting from action a. Finally, there is a payoff function $u_i{:}Z \rightarrow$ assigning payoffs to players as a function of the terminal node reached and an information partition, that for each x, let $h(x)$ denote the set of nodes that are possible given what player $i(x)$ knows. Thus, if $x' \in h(x)$, then $i(x') = i(x)$, $A(x') = A(x)$ and $h(x') = h(x)$ (Levin, 2002).

The situation described above is could be represented by a "*Stackelberg game*" where one player is a "*leader*" and chooses an action from a set A_1 and the other a "*follower*", who informed of the leader's choice chooses his action from an action set A_2. A more realistic representation of the game would be to insert "*nature*" as a third player, who decides at the initial point of the game who plays first. Therefore, in our case the game will start with "*nature*" (N) deciding randomly who plays first. Next, depending the choice of "*nature*", Player 1 (*P1*) or Player 2 (*P2*) will choose his/her action following the choice of the second player to end the game (Fig. 1). Although Fig. 1 describes a rather abstract representation of the game to describe the