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Experimental evidence supporting simpler Action Point paradigms for car-following

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ABSTRACT

The Action Point theory is one of the paradigms that can be applied to understand and reproduce car-following behaviour. Several different approaches to this theory have been proposed, some more simple and others more complex. In particular, the reference point in this field is still the paradigm from Wiedemann, which requires the identification of four action-point thresholds. In this paper we review Action Point theories in order to highlight similarities and differences and to ascertain whether all the thresholds proposed by Wiedemann actually bind the driving behaviour. Based on a large-scale experiment in which car-following data were collected, we identified all candidate action points assuming that the more complex (four-threshold) theory holds. Then we tested these points with respect to the large data set of available observations, in order to check whether actual actions are performed at the points. The results show that very often simpler approaches better match the observed data and that in order to explain car-following behaviour it is sufficient in most cases to refer to two thresholds. The results obtained by real-world observation were also tested in virtual environments (two different kinds of driving simulators) and were confirmed.

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1. Introduction

Modelling driving behaviour represents a crucial task for many applications in transportation. Three main areas can particularly benefit from an enhanced knowledge of driving behaviour: accident analysis and prevention, microscopic simulation of traffic, and Intelligent Transportation Systems (ITS). Benefits for ITS are mainly expected in the field of Advanced Driver Assistance Systems (ADAS), where some assistance/control logics interact with drivers (and their behaviour) and where both drivers' expectations, and impacts of the innovations on drivers' behaviour have to be considered in order to improve: (a) the effectiveness of the solutions; (b) driving (and traffic) safety and (c) acceptance of technological solutions.

Modelling of driving behaviour is based on two fundamental requirements. On the one hand, theoretical frameworks and paradigms are needed. On the other, observation tools and data are required in order both to develop/validate theories and to identify modelling parameters for practical applications. If the research focus is on disaggregate driving behaviour rather than aggregate traffic behaviour, the best source of information is based on individual vehicle data (IVD), as typically obtained by instrumented vehicles (IVs). An IV can be described as a standard vehicle where the kinematics, the interaction with surrounding vehicles and the vehicle–driver interaction are recorded for subsequent analysis. The possibility of observing only the kinematics of IVs, as allowed by some camera-based microscopic roadside observation systems like in the

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NGSIM project (Alexiadis, Colyar, Halkias, Hranac, & McHale, 2004), can lead to a reduced understanding of driving behaviour. Indeed, the possibility of observing the kinematics of an IV is just a prerequisite and IVs are usually equipped with a large number of sensors. Multisensing approaches not only enhance the estimation of the *ego-kinematics* of the controlled vehicle (Bifulco, Pariota, Simonelli, & Di Pace, 2011), but also allow detection of the surrounding traffic conditions and direct monitoring of on-board interaction between the driver and the vehicle, generally via the controlled area network (CAN). The overall result is a more comprehensive observation and enhanced understanding of driving behaviour.

Different aspects of driving behaviour can be analysed thanks to the data collected by means of IVs. At least two of these aspects are relevant to the field of ADAS: the longitudinal and lateral control of the vehicle. Lateral control involves manoeuvres such as lane keeping, lane changing and overtaking. In the case of longitudinal control, various conditions are often considered, such as free flow, approaching, car-following, emergency braking, and stop and go. Of these, the car-following process has probably been the most extensively studied.

Car-following models estimate the kinematics of a following vehicle as a response to the stimuli of a leading one. These paradigms assume that the follower adapts his/her speed to the vehicle ahead. Though some models have been proposed with a look-ahead approach, that is, based on the influence of more than one vehicle in the leading platoon (see Hoogendoorn & Ossen, 2006, for an empirical analysis), most approaches assume that the phenomenon can be mainly explained in terms of the vehicle directly ahead. In practice, in these models, each update of the follower's kinematics is obtained by considering its instantaneous position, and the speed and some kinematic variables of the leader. An exhaustive review of car-following models lies beyond the scope of this work and can be found in Saifuzzaman and Zheng (2014). According to this review, car-following paradigms can be classified, depending on their basic approach, in *Engineering* models and *psycho-physical* paradigms. This is a not new classification that Saifuzzaman and Zheng argument and develop, and that is perhaps the most widely accepted in the scientific literature.

Engineering car-following models apply Newtonian laws of motion to approximate car-following behaviours. The most studied model in this stream is probably the *stimulus–response* model by Gazis, Herman, and Rothery (1961), developed at the General Motors labs in Detroit. Several other relevant approaches are the *safety-distance* model of Gipps (1981), or the *desired measures* model proposed by Treiber, Hennecke, and Helbing (2000). Other approaches have emerged from the applications into the car-following behaviour studies of bio-inspired artificial intelligence concepts such as Artificial Neural Networks (Colombaroni & Fusco, 2014), fuzzy-logic (Kikuchi & Chakroborty, 1992) or cellular automata (Bham & Benekohal, 2004).

Models based on *psycho-physical* paradigms have been developed from human-factors studies. They move from the assumption that *Engineering* models are unable to characterise the process of human thinking (and solving) associated to the *driving problem*. As well addressed also in Saifuzzaman and Zheng, even if several attempts to embed human behaviours into *Engineering* models have been carried out (recently Pariota, Bifulco, & Brackstone, 2015 on-line publication), *psycho-physical* paradigms are characterised by quite peculiar (and convincing) fundamental assumptions on the human behaviour. As an example, drivers are assumed to adopt a satisficing performance evaluation strategy, rather than an optimal one (Boer, 1999), that means humans are often incapable of identifying and implementing optimal control strategy (Zgonnikov & Lubashevsky, 2014); moreover, are they can be observed to do not apply a continuous control (Wagner, 2011).

All the previous does not prevent from arguing that the *stimulus–response* and/or the *fuzzy-set* (or some other) approaches can also be considered to have a psycho-physical nature and both pros and cons can be debated on this point. However, this is mainly a definitional point, which arises from the attempt to give an ordered classification of the proposed models. Moreover, it should be clearly stated that cases could exist whose basic assumptions can blur. For example it could be proved that stimulus reaction model by Michaels (1963) that will be presented later (as a *psycho-physical* paradigm) is equivalent to the formulation of GHR model with sensitivity proportional to the inverse square of spacing, which leads to the Greenshields model in a stationary traffic state (Saifuzzaman & Zheng, 2014).

Within psycho-physical models, the action point (AP) approach seeks to describe the behaviour of a follower with respect to several thresholds, applied to the perception of different influencing stimuli coming from the leader. The AP paradigm has also been applied to microscopic traffic modelling (e.g. VISSIM), inspiring several researchers (Hoogendoorn, Hoogendoorn, & Daamen, 2011). Recently, Bifulco, Pariota, Brackstone, and McDonald (2013) took a step forward in exploiting AP theory in the field of ADAS with the introduction of the *car-following waves* concept.

The most widely used formulation of AP theory was proposed by Wiedemann (1974), even if earlier (and simpler) approaches were proposed by Barbosa (1961) and Todosoiev (1963). The latter models are introduced in Section 2, where Wiedemann's theory is shown to be more general but more complex, as it requires identification of two further AP thresholds. Some experimental evidence is analysed in order to investigate the proposed approaches under a new light and identify a good trade-off between their generality, robustness and simplicity. Section 3 presents the experimental campaign in which data were collected, carried out during the Italian DriveIN^2 research project (Bifulco, Pariota, Galante, & Fiorentino, 2012). Data are first of all analysed in terms of *kinematically*-identified APs (as in Brackstone, Sultan, & McDonald, 2002), and then validated versus observed actual drivers' actions. The discussion of the results allows some appropriate conclusions to be drawn, the most important being that that in the great part of the cases (at least among those observed in the DriveIN^2 campaign) it is worth adopting a simpler approach. This results confirm, by using a different kind of analyses (actions on pedals) and a different dataset, the ones obtained in Bifulco et al. (2013), where only kinematic observations were adopted. Another main contribution of this paper is to propose to ascertain from candidate APs and actual ones. Moreover, the carried out analyses are based on a (much) more extended naturalistic (road) survey experiment with respect to Bifulco et al. (2013), as well

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