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Autonomous and Connected Cars: HCM Estimates for Freeways with Various Market Penetration Rates

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Abstract

Major IT companies and vehicle manufacturers have announced their plans for autonomous driving technology. Autonomous light duty vehicles are often referred to as "driverless cars" (DLC). These technologies intend to partly or fully replace driving by combining navigation systems, artificial intelligence, in-vehicle sensors, roadside ITS and traffic monitoring data, vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications.

The absence of perception errors and the minimal perception and reaction time of DLC enable them to maintain shorter headways, to apply consistent acceleration and deceleration rates, and to optimize the use of gaps. In theory, freeway operations and level of service (LOS) can be impacted to a substantial but yet unknown degree by the DLC.

The Highway Capacity Manual (HCM).is a static and macroscopic methodology for assessing various traffic flow facilities. Its 2010 edition is not adjusted for the presence of DLC on highways, however, several of its parameters are sensitive to differences in perception and reaction times, headways, etc. An investigation was conducted to assess the likely changes to traffic flow characteristics that may result from the introduction of DLC. The focus of this paper is on expressways, that is, on HCM analyses of basic freeway segment and freeway weaving segment.

DLC is able to increase capacity (c), the maximum service flow rate (MSF_i), the adjustment factor for unfamiliar driver population (f_P), passenger-car equivalent (PCE), and the proportion of heavy vehicles (P_T).The combined benefits improve LOS. The results from the case studies show that the impacts of DLC on HCM parameters are tiny if the DLC have a very small market share. Two types of DLC are considered in this paper: Autonomous DLC, and Connected DLC with V2V and V2I. On a basic freeway segment the Autonomous DLC improves LOS from D to C when its share in traffic reaches 7%. The same case study shows that the Connected DLC improves LOS from D to C when its share in traffic reaches 3%.

Keywords: driverless, autonomous, connective vehicle, freeway operations, HCM, LOS

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1 Introduction

Driverless cars (DLC), also known as autonomous vehicles or self-driving cars is an emerging technology that has been growing rapidly in the past few years. As Google, Uber and Apple, along with other auto manufacturers (e.g., Audi, BMW, Mercedes, Tesla) are making progress on the road towards driverless transport, other major automakers such as Nissan, Toyota and VW are focusing on developing vehicles with certain automated driving functions. However, details of DLC have not been revealed to the public yet. In the early stage of DLC implementation, traffic composition will be mostly manually-driven vehicles with several vehicles with automated driving functions and some DLC. It becomes significant to study the traffic flow performance when DLC with different settings are mixed in traffic.

Several studies on DLC and their impact on traffic operations focus on modeling car-following features based on a variety of assumptions about DLC capabilities. For example, Adaptive Cruise Control (ACC) (Kesting, et al., 2005) was shown to eliminate traffic congestion with 30% share in traffic. The ACC was applied on a classic macroscopic traffic flow mode and proved to greatly improve capacity (Baskar, et al., 2009). Using microscopic simulation, Cooperative ACC (CACC) vehicles are found to be able to relieve congestion even with a low proportion of CACC vehicles in traffic (Arem, 2015).

The Highway Capacity Manual (HCM) has been established as a standard tool for the operational analysis for highways and related facilities (HCM, 2010). It provides deterministic and macroscopic methodologies for estimating measures of traffic operational such as speed, density and delay, which are used as the foundation for economic and environmental analyses. For uninterrupted flow facilities, density is used as an indicator of the level of service (LOS), and modeled as a function of capacity, flow rate, and average speed. These parameters are adjusted by a set of factors describing drivers' behaviors towards lane and shoulder widths, unfamiliar routes and lane change. However, DLC is not sensitive to these factors due to its navigation, LIDAR and programmed car-following systems (Shi and Prevedouros, 2014) (Kesting, et al., 2005). An evaluation of traffic performance with DLC in traffic can be conducted using the HCM methodology.

DLC features combined together are meant to improve headway, which can also be used to adjust the macroscopic measures defined in HCM. Because so little is known about DLC, the HCM approach adopted herein keeps things simpler and grounded on flow fundamentals for assessing the potential of DLC on LOS. Considering current degrees of automation, DLC can be classified into two types: Autonomous DLC (A-DLC) and Connected DLC (C-DLC). This paper proposes an analytical assessment of the potential capacity enhancing and LOS improving opportunities of DLC based on modified formulations of standard HCM analysis for freeways. Two key variables are defined to quantify the features of DLC:

h_D is the car-following headway of DLC, which represents their technical capability.
P_D is the proportion of DLC in the traffic stream.

The paper is organized as follows: Section 2 establishes the connections between HCM parameters and DLC features, followed by adjusting those parameters using quantified DLC features in section 3. Section 4 presents case studies on Basic Freeway Segment and Freeway Weaving Segment to demonstrate the potential effect of DLC on LOS. Results are compared between A-DLC and D-DLC under different traffic composition shares. Considering the varieties of DLC features, sensitivity analyses are conducted in each case study. Section 5 presents discussion and brief conclusions.