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Developing passenger car equivalents for freeways by microsimulation

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Abstract

In this paper a method of estimation of the passenger car equivalents for heavy vehicles on freeway is described. The variation in traffic quality was evaluated basing on a traffic demand characterized by different percentages of heavy vehicles. Aimsun micro-simulator was used to isolate traffic conditions difficult to capture on field, to replicate them to have a number of data as much as possible numerous, and to quantify the fundamental variables of traffic flow, namely the speed, flow, density, for a test freeway segment. Model calibration was accomplished by using traffic data collected at observation sections on the A22 Brenner Freeway, Italy. In order to check to what extent the model replicated reality, the validation of the calibrated model was also addressed. Simulation data were used to develop the relationships among the variables of traffic flow and to calculate the passenger car equivalents for heavy vehicles by comparing a fleet of passenger cars only with a mixed fleet characterized every time by different percentages of heavy vehicles. Despite the exploratory nature of this study, some implications can be drawn: PCE estimations are small at low flow rates and increase with increased flow rates due to at low volumes there are few passenger cars that can be influenced by heavy vehicles.

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Keywords: microsimulation; freeways; passenger car equivalents; heavy vehicles; calibration, Aimsun

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1. Introduction

Passenger car equivalents (PCEs) for heavy vehicles are used to convert a mixed vehicle flow into an equivalent flow composed exclusively of passenger cars. In transportation engineering their calculation is relevant to capacity and level of service determinations, since incorporating the impact of heavy vehicles on freeway operations make the performance analysis of a specific road infrastructure more accurate. Heavy vehicles, indeed, differ from passenger cars for size and acceleration/deceleration abilities; these different (physical and operational) characteristics can result in driving behaviour different by each vehicle class in a traffic stream where the distribution of vehicles among the classes is, in any case, influenced by location and time. Due to their larger size and manoeuvring difficulties, heavy vehicles also impose a psychological and practical impact on near drivers in adjacent lanes (Anwaar et al., 2011; Roess et al. 2014). The impact of heavy vehicles on freeway operations has been a topic of interest since the first edition of the Highway Capacity Manual (HCM). The recent versions of the HCM (2000, 2010) provide different values of passenger car equivalents for heavy vehicles depending on the percentage of heavy vehicles, different grades, and grade length for freeways and highways. Addressing heavy vehicles effect on different types of highway facilities, passenger car equivalents are intended for use in level-of-service (LOS) analyses. However, assuming the values of passenger car equivalents as the HCM (2010) suggests, underestimation or overestimation of the effect of heavy vehicles on the quality of the traffic flow may happen.

Various methodologies have been used to calculate the passenger car equivalents for heavy vehicles for different types of facilities. Definitions of equivalency based on the heavy vehicle effect on different parameters have been proposed. The determination of passenger car equivalents, indeed, include methods based on flow rates and density (John and Glauz, 1976; Huber, 1982; Krammes and Crowley, 1987; Sumner et al., 1984; De Marchi and Setti, 2003; Webster and Elefteriadous, 1999), headways (Werner and Morrall, 1976; Anwaar et al., 2011), queue discharge flow (Al-Kaisy et al., 2002), speed (Hu and Johnson, 1981), delay (Craus et al., 1980; Cunagin and Messer, 1983), volume/capacity ratio (Linzer et al., 1979), platoon formation (Elefteriadou et al. 1997; Van Aerde and Yagar, 1984; Al-Kaisy et al. 2002) and travel time (Keller and Saklas, 1984). However, significant differences can be found among the values of PCE factors from different methods especially in heterogeneous traffic environment; see e.g. Adnana (2014). Only a few studies have been based on field data; most current published studies and researches used traffic simulation to obtain equivalent flows for a wide combination of flows and geometric conditions.

According to Webster and Elefteriadou (1999), in operational analysis of freeways PCEs calculations should be based on density, since it is used to define LOS for freeways (HCM, 2010). On this regard, Huber (1982) proposed a framework for PCEs derivation based on finding a flow rate of a base stream of passenger cars only and a flow rate of a mixed stream Q_M containing $Q_M{\cdot}p_T$ heavy vehicles and $Q_M{\cdot}(1 - p_T)$ cars, having the same level of a measure of impedance. Huber (1982), indeed, used some measure of impedence as a function of traffic flow to relate one traffic stream of heavy vehicles mixed with passenger cars and another traffic stream of passenger cars only. PCE values were related to the ratio between the volumes of the two streams at some common level of impedance (i.e. the density of both streams). Differently from Huber (1982), Sumner et al. (1984) measured the impedance by the number of vehicle-hours in the base and mixed streams, which is equivalent to density as measure of impedance; they used microscopic simulations to expand the Huber procedure to calculate the PCE of each type of subject vehicle in a mixed traffic stream taking into account the different types of heavy vehicles, in addition to passenger cars. Webster and Elefteriadou (1999), in their turn, expanded the work of Sumner et al. (1984) by including a wide range of freeway conditions and derived PCEs based on density. It is noteworthy that the HCM (2010) utilizes passenger car equivalents to estimate the effect of heavy vehicles on traffic stream behaviour under free-flow or undersaturated conditions. Moreover, these factors have been used to conduct analyses for all traffic conditions (from free-flow to congested-flow conditions). A growing body of recent empirical evidence suggests that the PCEs for undersaturated conditions can underestimate the effect of heavy vehicles after the onset of congestion (Al-Kaisy et al., 2005). One must say that the acceleration and deceleration cycles, as normally experienced during congestion or stop-and-go conditions, impose an extra limitation on the performance of heavy vehicles. On this regard, few studies have been conducted to explore the effect of heavy vehicles also for forced-flow conditions (Ahmed, 2010). Al-Kaisy et al. (2002) derived passenger car equivalents using queue discharge flow as the equivalency criterion; however, they are still far from a generalization in the results, albeit these findings were consistent with field observations as experienced by Yagar and Richard (1996).