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Estimating percent-time-spent-following on two-lane rural highways

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ABSTRACT

This study concentrated on estimating the percent-time-spent-following (PTSF) on two-lane highways. This measure is a key estimate of level-of-service in traffic engineering applications. Its evaluation to date has been based on simulations that yielded over-estimated values. The present study shows how to estimate this variable from easily obtained field data based on queuing theory. The estimates accord with opinions on yielding significantly lower values of PTSF that are expressed in the relevant traffic literature. An improved relationship between PTSF and two-way flow is provided by fitting the new estimates by means of the least-squares method.

1. Introduction

The level-of-service concept is commonly accepted in traffic engineering as a way to evaluate the quality and characteristics of flow on various facilities. For example, it is needed for decision-making on adding lanes, re-aligning highways and conducting safety analyses. This paper shows that utilizing relatively simple operations research methodologies may contribute directly to advancing important traffic engineering issues that have not previously been explored.

One of the recommended measures of the level-of-service of two-lane rural highways, according to the leading manual of traffic analysis, the Highway Capacity Manual (HCM, 2000), is the proportion of time that fast vehicles travel in platoons behind slow vehicles. This proportion is typically measured by the Percentage of Time Spent Following (PTSF). In reality, it is rather difficult to measure PTSF because of the complexity of collecting data for fast-traveling vehicles that follow slower vehicles. This means that direct measurement, which would also necessitate the use of complicated equipment would be prohibitively expensive, if not practically impossible, to make. An alternative would be to calculate PTSF from simulation runs; however, this approach has disadvantages, mainly because it requires assumptions regarding traffic characteristics, particularly the behavior of drivers in passing maneuvers. Previous studies have not provided other alternative analytical approaches for calculating PTSF values. The present research offers a theoretical model to determine PTSF values for different flow conditions from readily available and easily observed traffic data. The new model provides values that are significantly lower than the HCM model, which is known to be overestimated (e.g., Harwood et al., 2003; Luttinen, 2001).

A few assumptions must be made to arrive at an analytical model to estimate PTSF. Although these simplifying assumptions are not often fulfilled, they are fairly close to reality in some conditions. Without any assumptions, it becomes impossible to solve the model analytically; the assumptions in this work are necessary to derive a theoretical formula whose arguments are easily measurable quantities. Furthermore, it will be shown that the results of the model's predictions of PTSF provide values that are lower than the HCM values.

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2. Background

Previous studies that have dealt with estimating PTSF include the following: The Highway Capacity Manual (HCM, 2000, and previous editions) uses this variable as the main measure of the level-of-service of two-lane highways; the model provided is based on simulation runs with the TWOPAS model (Dixon et al., 2003). Several studies (e.g., Harwood et al., 2003; Luttinen, 2001) suggested that the HCM values for PTSF were overestimated. A recent study (Al-Kaisy and Durbin (2007) also suggested that the HCM values of PTSF are overestimated and proposed a proxy measure of "percent following" (PF), which is an estimate of the percentage of fast vehicles trapped in platoons at a specific location. However, the proposed measure is for a static observer; it is not for the time-spent in platoons but rather for the number of vehicles in platoons. A previous study by the present authors (Polus and Cohen, 2009) suggested using PTSF as one of the potential measures of level-of-service, giving an estimate of its value as a function of the two-way flow on two-lane highways and based on easily observable quantities. That study focused mainly on a comparison of several measures of level-of-service and did not give a detailed explanation of the assumptions and the PTSF model's details. Additionally, it was based on only 30 data points. Since then, significant additional data were collected and analyzed. Additionally, 71 new data points (in addition to the previous 30) were added. Each of the 101 data point represents 1-h of one-way traffic. The current paper focuses on the details and assumptions and various conditions for estimating PTSF.

3. Elements of the model

The following symbols are used in the paper:

Symbol	Meaning
h	headway
$\bar{h}$	average headway
L	average number of fast vehicles behind a slow vehicle
N	number of headways between two platoons
$\overline{N}$	average number of headways between two platoons
Q	number of headways inside a platoon
$\overline{Q}$	average number of headways inside a platoon
s	average speed of fast vehicles
u	average speed of slow vehicles
V	flow, average number of passenger-car equivalents per unit time
W	average time between joining a platoon and passing the first vehicle
θ	average travel time between two platoons
λ	arrival rate at the back of a moving queue
π	probability that a slow vehicle has no following platoon
ρ	traffic intensity, a parameter of the geometric distribution

Three assumptions were made during the development of the model: First, the speeds of fast and slow vehicles are assumed to be constant, denoted by s and u, respectively. Second, the flow of traffic is along an infinite homogeneous section, without any entrances or exists and with similar geometry. Third, the flow operates in a steady-state condition.

Fig. 1 shows schematically several vehicles in two platoons and three vehicles between the platoons. Vehicles trail one another in a platoon because faster vehicles are impeded by slower vehicles and there is difficulty in passing because of on-coming traffic. The figure shows the headways between vehicles, which are the time durations between two consecutive passing vehicles measured by a static observer. Note that the headways themselves are random. The number of headways inside a platoon is denoted by Q; e.g., $Q = 2$ in the second platoon in Fig. 1. The number of headways outside the platoons is denoted by N; e.g., $N = 4$. The easily observable values of Q and N are the inputs for the proposed new estimate of PTSF.

It is possible to consider each platoon as a one-server queuing system, in which "service time" is the time interval spent by the fast vehicle in the first position just behind the impeding vehicle. Fast vehicles that join the back of the platoon are the

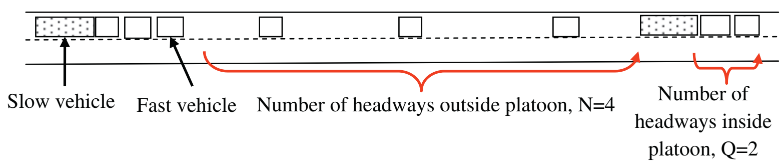

Fig. 1. Schematic diagram of one direction of a two-lane highway with two platoons and three vehicles between platoons.