

Preferred Time-Headway of Highway Drivers

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Abstract

The preferred time-headway of drivers in highway conditions is related to the likelihood of rear-end collisions. It is also important for the design of intelligent highway vehicle systems, including adaptive cruise control and collision-avoidance or collision-warning systems. We studied traffic data from a section of southbound highway 101-- a heavily commuted eight-lane freeway between San Francisco and the Silicon valley in California. We observed two parameters that drivers regulate during free flow, rush hour, and heavy traffic conditions: (1) the speed of their vehicle and (2) the time-headway to the preceding vehicle. During free flow traffic, the preferred speeds show low variation within lanes, but large variations from lane to lane, with lane-one (leftmost lane) drivers having average speeds that are ~18 mph faster than lane-four drivers. During rush hour traffic, the time-headway between vehicles varies between 1 and 2 s for a range of traffic speeds. For all traffic conditions a lower limit of 1 s is seen in time-headway, even when traffic volume does not push drivers toward tight spacing. The lower limit of 1 s is consistent with what was found in several previous studies, but is significantly shorter than the 3 s headway that is recommended by driving manuals. The short time-headways observed are within the limit of typical reaction time for braking by alert drivers, but probably lead to occasional accidents given variability in reaction times, decisions, and vehicle braking capabilities, especially when preview information is not available.

Index terms: time-headway, highway driving, vehicle control

I. INTRODUCTION

Rear-end collision is a major type of car accident, accounting for about 24% of all accidents involving two or more vehicles in the USA in 1990 (McGehee, Dingus, Horowitz, 1992). To avoid rear-end collisions, it is important to drive at a safe speed and maintain a sufficient time-headway to the vehicle ahead. Many researchers have attempted to examine what the safe speed and time-headway should be so that drivers could respond safely to a deceleration of a vehicle in front, and a variety of models have been proposed for car following behavior (see Rothery, undated). Using a computer model that draws on visual closing information, Lee (1976) found that safe time-headway depends on speed, braking capacity, and visibility, and in general should be larger than 2 s. This is consistent with the typical 3 s safety rule specified in driving manuals (e.g., California Driving Manual, 2001). However, actual driving data do not correspond to these numbers. Treiterer & Nemeth (1970) found that nearly 50% of headways in interstate traffic were between 1 and 2 s, and over 20% were below 1 s. von Buseck, Evans, Schmidt & Wasielewski (1980) reported a median time-headway of approximately 1.4 s in urban interstate traffic. Similar findings have emerged from studies with driving simulators: van Winsum & Heino (1996) found that when

drivers' speed was within the range of 40-70 mph, their preferred time-headway was kept at 1 s. They further indicated that drivers following with short time-headways tend to be better at programming and executing the intensity of braking to required levels.

To find drivers' preferred time-headway in real-world driving across a wide range of speeds and conditions, we obtained traffic flow data for December, 1999 from Caltrans (the California Department of Transportation) for a section of highway 101 south of San Francisco. We quantified the parameters of speed and headway, differentiating for traffic conditions during the day and segments of drivers by lane choice in order to provide a description of how drivers regulate speed and time-headway.

II. METHODS AND DATA

2.1 Data Collection

Underneath the pavement of many highways in the United States are inductive loop detectors—loops of wire that operate on the principle of changing inductance caused by the motion of a large conductor (e.g., a car or truck). These loop detectors record three traffic parameters: volume (Q), occupancy (σ), and speed (v). The passage of a vehicle over a detector generates an electrical pulse; these pulses are counted by the detector system and are recorded as traffic volume in the units of vehicles/hr. By comparing the duration of the pulse to the time between pulses, the system calculates a percent of time that a vehicle is over the detector, which is the occupancy. A pair of loop detectors separated by a short distance can determine the speed of car by measuring the time between pulses, since the distance between detectors is known.

2.2 Raw Data

We analyzed data from loop detectors in each of four southbound lanes for a section of highway 101. The detectors recorded the three traffic parameters at 30 s intervals. Figure 1 shows volume, speed, and occupancy for lane 3 across the morning hours. Based on examination of the data, we defined the interval from 5:00 to 6:30 AM as “free-flow traffic” with an average speed of approximately 70 mph and low occupancy. At 7:15 AM the speed drops sharply to approximately 30 mph until 8:45 AM; this “rush hour traffic” is also marked by increased occupancy and high traffic volume. From 10:00 to 11:30 AM, during “heavy traffic” the traffic volume is high, but there is reduced occupancy and increased speed.

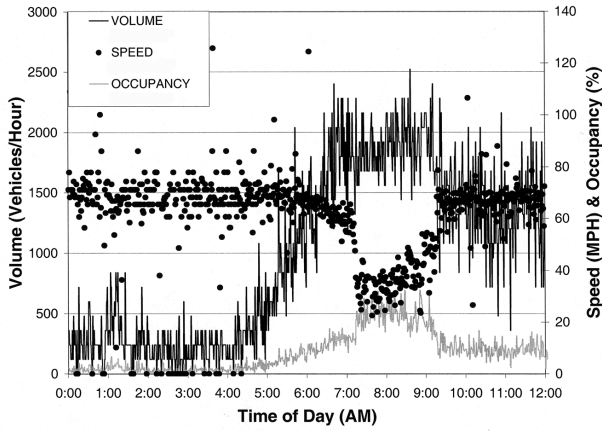


Figure 1. Traffic volume, speed and occupancy for lane 3 across the morning hours.

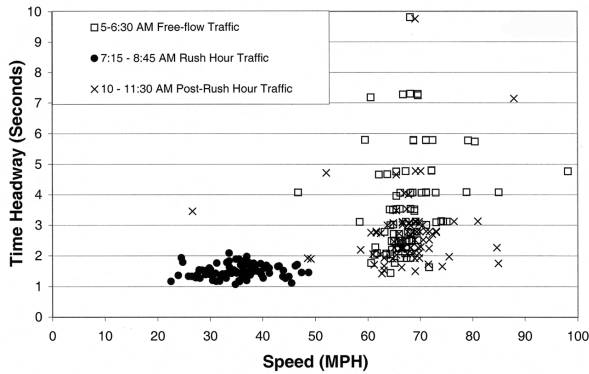


Figure 2. Time-headway as a function of speed for lane 3.

2.3 Processed Data

We converted the raw data into parameters that an individual driver can control: the driver’s speed and the following distance, which is quantified in terms of time-headway. The speed, which the driver regulates with acceleration and deceleration, is directly taken from the raw data. With the caveat of effective vehicle length¹, the time-headway between vehicles is calculated as:

$$T_h = (1/Q) * (1 - \sigma) \quad (1)$$

Figure 2 shows the time-headway as a function of speed for lane 3, where the symbols show the pre-rush hour, rush hour, and post-rush hour traffic conditions. Similar patterns were obtained for the other lanes, with generally higher speeds in the “fast” lanes. There is a clear split between traffic conditions. The free flow traffic has higher speeds (~70 mph) and a wide range of time-headways. This is characteristic of drivers operating near the maximum speed

¹ The physical length of a car (L_c) is increased by the size of the detector (L_D), giving it an effective length of $L_c' = L_c + L_D$. This length divided by the total length between vehicles—front bumper to front bumper—is the occupancy measured with the loop detectors.

(the posted limit is 65 mph) and spacing themselves in bunches on the roadway. Conversely, rush hour traffic has a narrow range of time-headways (1-2 s) across a range of reduced speeds from 20 to 50 mph. The time-headways show a high degree of uniformity; all of the drivers have ordered themselves in an evenly spaced, tight traffic pattern. The post rush hour traffic is a combination of short time-headways and high speeds.

III. DISCUSSION

3.1 Driver Control

The clear split illustrated in Figure 2 as discussed in the above section suggests that traffic patterns could be simplified into two regimes of traffic conditions—free flow traffic and congested traffic.

Free-flow traffic: In free-flow traffic, drivers choose a constant preferred speed. The time-headway between vehicles ranges from the minimum number 1 s to values based on the volume of traffic.

The preferred speed depends on physical parameters characteristic of the roadway and psychological parameters characteristic of the driver. The physical parameters consist of the posted speed limit, road difficulty (grade, lane size, and turns), environmental conditions (weather) and any other conditions that limit an unconstrained driver’s maximum speed. The travel speed will also depend on the preference of the driver. Drivers tend to drive somewhat faster than the speed limit, and people who drive in lane one tend to drive at a faster speed than lanes two and three.

Congested Traffic: In congested traffic, the time-headway approaches the typical lower bound of roughly 1 s. Drivers attempt to reduce gaps and thus the possibilities of downstream lane changes. The velocity is dependent on the downstream conditions (e.g. on-ramps, off-ramps, and number of lanes) and other impedance factors, which may slow the traffic flow.

In congested flow, drivers tend to bunch closely together with a time-headway that approaches a lower limit of generally safe handling. The basic task is to keep up with the vehicle ahead without hitting it (Rothery, undated). Perhaps the most dramatic aspect of Figure 2 is the roughly constant time-headway seen in rush hour traffic. For a 1.5 hr period of time, drivers are well bunched into a pack with separations of between 1 and 2 s. This time-headway remains constant with vehicle speeds from 20 to 60 mph. During heavy traffic, the factors that limited the speed during rush hour have been removed and the traffic speed approaches the preferred speed. Heavy volume is still maintained and the time-headways approach the lower bound. In Figure 2, heavy traffic data is clustered at the intersection of the pre-rush hour and rush-hour data. Thus, during this time drivers push both the limits of preferred speed and time-headway.

3.2 Driver Segmentation by Lane

Although the patterns of speed and time-headway are similar across lanes, there are systematic differences that reflect individual driver preferences. The top portion of Figure 3 shows that mean speed is higher as one moves towards the center or “fast” lanes, as expected, except when rush hour forces all the speeds to be low. Rush hour also eliminates inter-lane variations in time-headway (bottom of Figure 3), but drivers in the fast lanes generally choose shorter time-headways than slower-lane drivers when traffic conditions permit higher speeds (except for lane 1 in free flow condition). Thus, 1-2 s time-headways are typical in all lanes under high-volume traffic conditions, but some drivers will choose the lower speeds and longer headways prevalent in the slower lanes outside of rush hour.

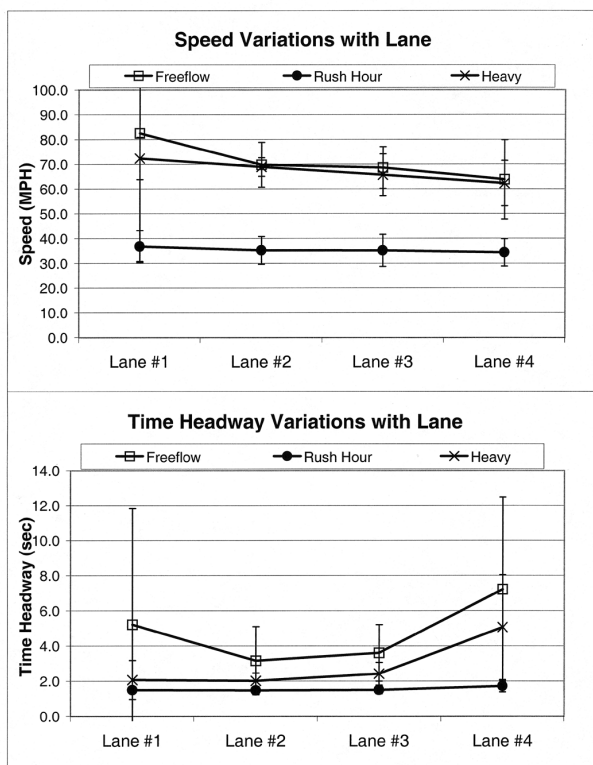


Figure 3. Mean speed (top) and time-headway (bottom) variations across lanes at different traffic conditions.

IV. CONCLUSIONS: SAFE FOLLOWING TIME-HEADWAYS AND SPEEDS

The 1 s time-headway threshold found in our study for rush hour and heavy traffic agrees with previous findings. The typical range of time-headways observed (1-2 s) matches the range of reaction times observed in emergency braking (e.g., Lerner, 1993; Olson, 1989; Olson & Sivak, 1986). Certainly it is no coincidence that this match --maintaining a time-headway that matches one’s response capability -- is just adequate for avoiding collisions, as long as a driver is attentive and alert and the vehicle has good braking. Indeed, the fact that most highway driving is conducted successfully (without rear-end collisions) shows that drivers

are making a reasonably appropriate decision when they choose their speeds and headways. This is consistent with the observation that people generally act in a reasonably adequate manner, not maximizing safety or minimizing risk, but rather improving performance as far as the situation appears to allow (Ayres, Wood, Schmidt & McCarthy, 1998). In a similar way, drivers are generally (but not always) responsive to traffic and situational demands when they use cellular telephones (Ayres, Humphrey & Murray, 1999).

Herein lies a quandary for highway safety planning: Normally adequate behavior such as maintaining a 1-2 s time-headway does not eliminate collisions in the absence of useful preview information (e.g., being able to see the slowing of vehicles further ahead than the one that is immediately in front). Drivers look away from the forward environment for typically 1-1.5 s per glance in order to conduct in-vehicle tasks or check rear view mirrors (again, generally but not always safe; Ayres, Donelson, Brown, Bjelajac & Van Selow, 1996); such a glance at the wrong time can eliminate the safety margin represented by the time-headway. Even if a driver is looking ahead, he or she may not immediately brake as forcefully as the car ahead to avoid an accident. For example, at highway speeds, the perceptual information that is available when the headway distance to a vehicle ahead is decreasing often is inadequate for drivers to judge the rate of time-headway change (or time to collision) soon or accurately enough to avoid collision, especially at night (Ayres, Schmidt, Steele & Bayan, 1995).

The data presented here, as in previous studies, shows that drivers are most likely to accept time-headways of 1-2 s. Intelligent Transportation Systems devices that set shorter times (in order to increase road capacity) will likely make drivers feel uncomfortable because they sense that they cannot respond adequately if they need to intervene or take control. On the other hand, imposition of time-headways substantially longer than 2 s will seem excessive to most drivers, even though highway safety might be improved (at the cost of lower roadway capacity). Differences between people in their preferred speeds and time-headways add further complication to safety planning.

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