Car-Following Headways in Different Driving Situations: A Naturalistic Driving Study

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Abstract

Car-following is the most frequent driving scenario, and is characterized by headway. Headway is a measure of the temporal space between two vehicles. It relates to the time available for a driver to react, and is a safety measure of car-following behavior. The characteristics of car-following headways remain poorly understood in China and this has a secondary effect on road alignment design, road capacity, traffic flow stability, traffic safety, and the design of many in-vehicle systems. With high validity naturalistic driving data, this study investigated the distribution of drivers' car-following headways and how drivers would adjust their headways due to level of operating speed, visibility, roadway type, and traffic density. From 60,689 km of naturalistic driving data, 1,489 car-following events were identified. Headways were then extracted and statistically compared across different driving situations to quantify changes in car-following headways as a result of driving situations. The results of this study show that (1) the distribution of car-following headway was similar to a lognormal distribution; (2) drivers tended to maintain longer headways in slow-speed driving, nighttime, surface roads, and dense traffic conditions. The results of this study may be valuable for understanding car-following behavior and traffic simulation.

INTRODUCTION

Car-following is the most frequent driving scenario. It refers to the situation in which a vehicle's speed and longitudinal position are influenced by the vehicle immediately ahead of it in the same travel lane (Ranney 1999). Car following forms the cornerstone for many areas of research including (a) traffic simulation, where the car-following model controls the motion of the vehicles, and (b) the functional definition of the Advanced Driver Assistance System (Brackstone and McDonald 1999).

Car-following is characterized by vehicle headway (Ranney 1999), which is a measure of the temporal space between two vehicles. Headway is defined as: the elapsed time between the arrival of the lead vehicle (LV) and the following vehicle (FV) at a designated test point

(Ben-Yaacov et al. 2002). It relates to the time available for a driver to react, and is a safety measure of car-following behavior. Since the average of vehicle headways is the reciprocal of flow rate, vehicle headways represent microscopic measures of flows passing a point. To some extent, the minimum acceptable mean headway determines the roadway capacity (Zhang et al. 2007). The characteristics of car-following headways remain poorly understood in China and this has a secondary effect on road alignment design, road capacity, traffic flow stability, traffic safety, and the design of many in-vehicle systems (Jiang and Lu 2015).

Studies of car-following behavior have been undertaken since the 1960s (Jiang and Lu 2015). However, research in past years has been limited by field data. Field test studies conducted on test tracks have bias from limited driving situations and lack of real world driving data. Naturalistic Driving Study (NDS) has given a new horizon to the observation of driver behavior. NDS is a relatively new research method using advanced technology for unobtrusive in-vehicle recording of driver behaviour during ordinary driving in everyday traffic situations (FESTA 2008). With NDS, driver behavior is observed as it occurs in the full context of real-world driving, and vehicle kinematic data (e.g., acceleration, velocity, position) are recorded continuously at high resolution (Fitch and Hanowski 2012).

The ongoing Shanghai Naturalistic Driving Study (SH-NDS) is the first NDS project conducted in China. The data collection procedure started in December 2012; as of July 2015, 55 drivers and 133,458 km of driving data have been collected. The detailed driving data provide an unprecedented opportunity for investigating Chinese drivers' car-following behaviors.

This study seeks to investigate whether drivers adjust their headways due to operating speed, visibility, roadway type, and traffic density. Specifically, with driving data collected by SH-NDS, car-following periods were identified. Then, headways were extracted and statistically compared across different driving situations to quantify changes in car-following headways as a result driving situations.

DATA PREPARATION

Shanghai naturalistic driving study. The data used in this study were collected by the ongoing Shanghai Naturalistic Driving Study (SH-NDS) jointly conducted by Tongji University, General Motors (GM), and Virginia Tech Transportation Institute (VTTI). The SH-NDS aims to learn more about vehicle use, vehicle handling, and safety consciousness of Chinese drivers.

Five GM light vehicles equipped with SHARP2 NextGen Data Acquisition Systems (DAS) are used to collect real world driving data. The data collection procedure started in December 2012, planned to collect 90 licensed Chinese drivers' daily driving data, and ended in December 2015. Each participant drove the vehicle for two months.

Data acquisition system. The SHARP2 NextGen DAS includes an interface box to collect vehicle CAN data, an accelerometer for longitudinal and lateral acceleration, a radar system that measures range and range rate to the LV and vehicles in the adjacent lanes, a light meter, a temperature/humidity sensor, a GPS sensor for location, and four synchronized camera views to validate the sensor-based findings (Fitch and Hanowski 2012).

As shown in Figure 1, the four camera views monitor the driver's face, the forward roadway, the roadway behind the vehicle, and the driver's hand maneuvers. The frame rate of the four views of videos is 14.98 FPS, and the data collection frequency for accelerometer and radar system is 50 Hz. The DAS automatically starts when the vehicle's ignition is turned on, and automatically powers down when the ignition is turned off.

Figure 1. Four camera views for the SH-NDS.

Data description. As of July 2015, the SH-NDS collected 55 drivers' driving data. The data first had to be uploaded to VTTI's Naturalistic Driving Data Server. The data ingestion and prepress procedures were then conducted. Nineteen drivers' data were used for analysis in this study. The data set used represent 60,689 km and 4,573 trips of driving. The drivers' age ranged from 28 to 61 (mean = 40.9) with an average of 6.6 years of driving experience (range = 1 to 16).

METHODOLOGY

Car-following period extraction. Car-following periods were automatically extracted from the driving data to analyze drivers' car-following behaviors. The criteria used were mainly based on Ervin et al. (2005) and Higgs and Abbas (2013). The corresponding threshold for each criterion was adapted according to the characteristics of the data set.

The car-following filtering was an iterative process where initial criteria and thresholds were used. After the potential car-following periods were flagged, they were reviewed by videos to adjust the criteria and thresholds accordingly in order to obtain minimum noise.

As shown in Figure 2, a car-following period was extracted if the following criteria were met simultaneously:

- The radar target's identification number>0 and remains constant; this criterion is set to guarantee that the same lead vehicle is detected.
- 7m<range<120m, and speed of the research vehicle>5m/s; these two criteria were set to eliminate free flow and traffic jam conditions. In free flow or traffic jam conditions, the research vehicle and the lead vehicle do not have a close interaction. As car-following refers to a situation in which a vehicle interacts closely with the vehicle immediately ahead of it, therefore vehicles in free flow or traffic jam conditions are not in a car-following state.
- −2.5m<lateral distance<2.5m; this criterion guarantees that the following and leading vehicles are driving in the same lane.
- −2.5m/s<range rate<2.5m/s; this criterion eliminates scenarios in which the research vehicle is either rapidly closing in on, or falling back from, a lead vehicle.
- Length of car-following period>15s; this criterion guarantees that the research vehicle follows the lead vehicle for a long enough time period.

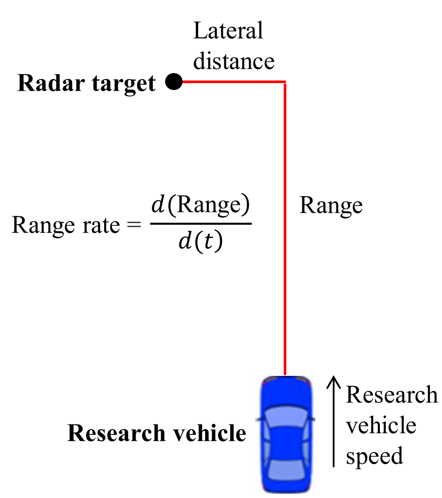

Figure 2. Radar target's position and motion with respect to the research vehicle.

Independent variables. The method of analysis was a linear mixed model, where drivers were treated as random effects to account for individual differences in driving behaviors. Table 1 summarizes the independent variables.

Table 1. Independent Variables

Variables	Conditions
Roadway type	Freeway, surface road
Ambient light	Daytime, nighttime
Traffic density	Sparse, moderate, dense
Travel speed	Slow, medium, high

To consider whether the traffic was interrupted, the roadways were divided into two categories: freeway and surface road. Freeways refer to roadways with limited access such as an urban expressway. Arterial, minor arterial, collector, and local roadways were labelled as surface roads. Roadway type and ambient light information were derived from front view video by an analyst.

Traffic density was identified through radar data. The radar system can track, at most, eight vehicles simultaneously. Using the position information of detected vehicles, the headway distance between each pair of lead and following vehicles was calculated and averaged. The reciprocal of average headway distance was taken as traffic density. Traffic density was further classified into three categories: sparse (<40 vehicles/km/lane), moderate (40–65 vehicles/km/lane), and dense (>65 vehicles/km/lane).

Travel speeds were pooled into three categories: slow (20–40 km/h), medium (41–65 km/h), and high (>65 km/h). The first category is typical of city driving and the last category is typical of freeway driving.

Weather condition was not included as an independent variable because only following events with ideal weather condition were used in this analysis. Considering the limited number of drivers, age, gender, and driving experience were not included as independent variables.

Dependent variables. The dependent variable was headway. Headway was calculated for each car-following event by dividing the following distance with the speed of FV, as show in Figure 3.

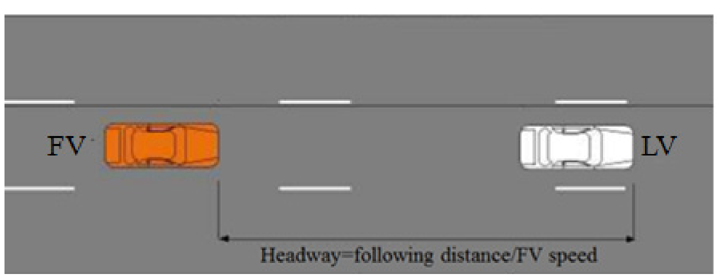

Figure 3. Calculation of vehicle headway.

RESULTS

A total of 1,489 car-following events were identified and used in this study, which represent 11.5 driving hours. Mean headway was calculated for all car-following events The analyses were performed with linear mixed models using the PROC MIXED procedure in SAS® 9.2. The statistical significance level was set at $\alpha = 0.05$.

Headway distribution. The distribution of mean headways for the 1,489 car-following events is shown in Figure 4. The mean and median values for the mean headways was 1.79 seconds and 1.62 seconds, respectively. Lognormal and normal distribution were fit on the headway data, and the distribution fit curves are shown in Figure 4. As can be seen, the lognormal distribution is more proper for the data, and the mu and sigma parameters estimated were 0.49 and 0.42 respectively.

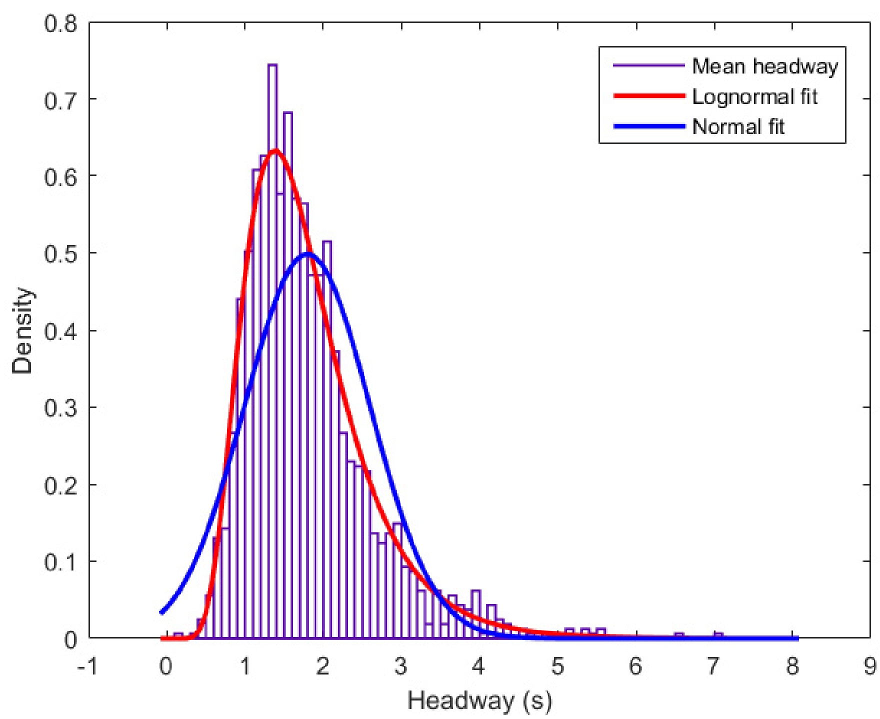

Figure 4. Distribution of the mean headways for the analyzed car-following events.

Travel speed. The analysis for mean headway showed significant main effects for travel speed ($F(2,30)=74.29$, $p<0.0001$). As shown in Figure 5, headway decreases as travel speed increases.

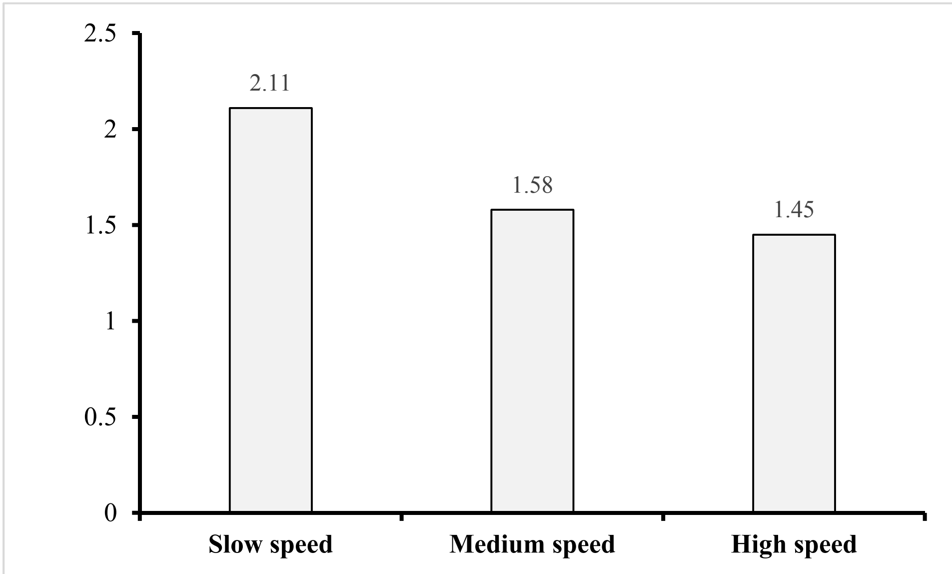

Figure 5. Car-following headway for different speed categories.

Ambient light. The main effects of the ambient light were significant, $F(1,14)=11.44$, $p=0.005$. As shown in Figure 6, drivers generally maintain longer headway in nighttime driving (least squares means = 1.79s) than in daytime driving (least squares means = 1.64s).

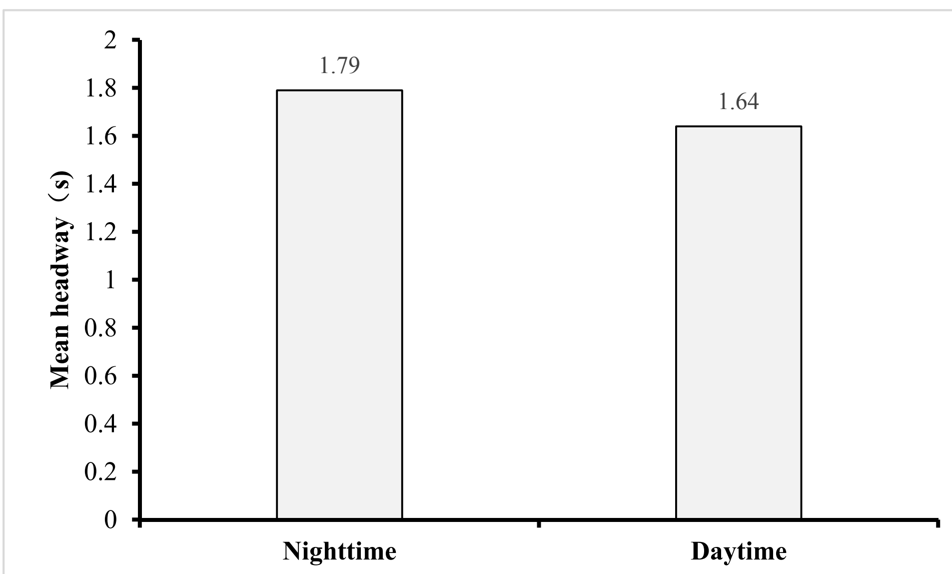

Figure 6. Car-following headway in nighttime and daytime driving.

Roadway type. The results showed that roadway type had a significant effect on car-following headway, $F(1,14)=38.39$, $p<0.0001$. As shown in Figure 7, car-following headway decreases from 1.86s to 1.57s from surface road to freeway.

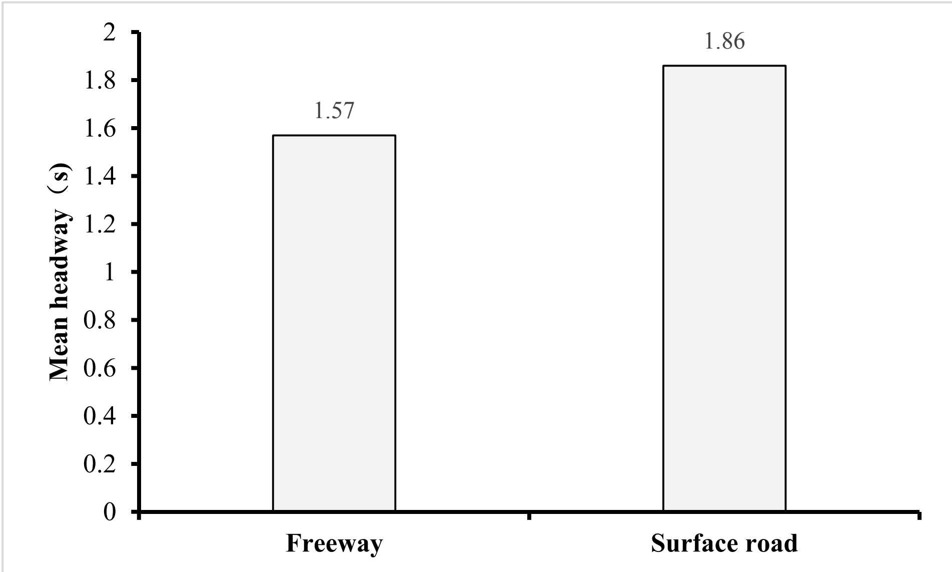

Figure 7. Car-following headway in freeway and surface road.

Traffic density. The analysis for mean headway showed significant main effects for traffic density ($F(2,34)=308.13$, $p<0.0001$). As shown in Figure 8, headway decreases as traffic density increases.

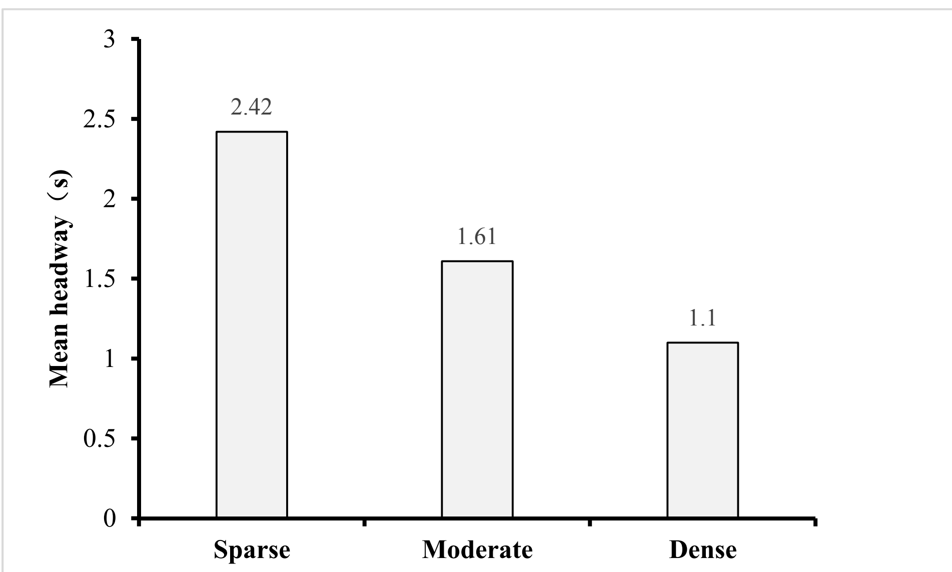

Figure 8. Car-following headway for different levels of traffic density.

DISCUSSION AND CONCLUSIONS

The car-following events identified in this study had an average time headway of 1.79 seconds, which is slightly less than the 1.86 seconds reported by Sayer et al. (2011) in America. This indicates that drivers in China may maintain a slightly shorter following distance than drivers in

America. The headway derived in this study obeys the lognormal distribution, which is similar to the conclusion of Jiang and Lu (2015).

The headway in nighttime driving was larger than that of daytime driving, which is easy to understand because it is more difficult to detect the speed changes of LV in nighttime than in daytime, and drivers kept larger headways in nighttime driving to give themselves more time available to respond to the speed changes of LVs.

Drivers maintained shorter headways on freeways than on surface roads. The possible reason for the short headways on freeways may be that drivers generally have greater speed on freeways than on surface roads, and headway decreases with the increase of driving speed. Another possible reason is that traffic flows in freeways are continuous rather than interrupted, and drivers may follow the LV more tightly on freeways than on surface roads.

This study investigated the distribution of drivers' car-following headways and how drivers would adjust their headways due to level of operating speed, visibility, roadway type, and traffic density. The results show that (1) the distribution of car-following headway was similar to lognormal distributions; (2) drivers tended to maintain longer headways in slow-speed driving, nighttime, surface roads, and dense traffic conditions. The results of this study are useful for better understanding car-following and traffic simulation.

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