Jurnal Kejuruteraan 32(2) 2020: 187-195
https://doi.org/10.17576/jkukm-2020-32(2)-02

A Study on Following Behavior Based on the Time Headway

Ehsan Ramezani Khansari, Masoud Tabibi* & Fereidoon Moghadas Nejad

Civil Engineering Department, Amirkabir University of Technology, Tehran, Iran
Corresponding author: masoud.tabibi@chmail.ir

Received 22 March 2020, Received in revised form 5 April 2020
Accepted 21 April 2020, Available online 30 May 2020

ABSTRACT

While time headway (TH) is a relatively simple variable and has been well researched, it has been less explored in non-lane-based traffic. The main aim of this paper is considering lateral distance in studying TH in a non-lane-based traffic flow. In this study driving behavior, speed-TH relationship, and the following threshold by using only TH in a non-lane-based flow were investigated. In a novel approach, THs were segmented into five intervals in a step by step manner from smallest to largest THs. Considering lateral distance led to divide driving behavior into intervals (based on the average TH), including: Unsafe (0-0.7 sec), non-lane-based car-following (0.9 sec), lane-based car-following (1.0 sec), overtaking TH (1.3 sec), and free driving (larger than 2.5 sec). It was founded that the TH of starting overtaking maneuver can be a good criterion to distinguish between following and free driving behavior. Also, in lane-based car-following behavior, when lateral distance between the following and preceding vehicles was not considerable, the smallest THs were seen. It has happened around the average speed of the flow as the driver may adopt lower THs because of the tendency to overtaking. Linear relationship was found between TH and lateral distance in non-lane-based car-following conditions. TH of non-lane-based behavior is less than lane-based and smaller THs would force drivers to apply lateral distance or vice versa.

Keywords: Time headway, Driving behavior, Non-lane-based behavior, Free driving

INTRODUCTION

The time headway (TH) or headway of vehicles is important in terms of safety and traffic flow characteristics, as one of the main goals of car-following models is estimating headway, implicitly or explicitly(Helbing and Tilch 1998; Lenz, Wagner, and Sollacher 1999; Aghabayk et al. 2014). For instance, Pipes and Forbes provided equations for speed-headway and speed-TH, respectively, to directly estimate the headway in a steady-state flow (Cao and Yang 2009; Brackstone and McDonald 1999). Although TH has been studied in many researches since 1936 (ADAMS 1936), it is still the main topic of many papers, for example, in 2002, Newell tried to developed Pipes model by considering the non-linearity (Newell 2002; Ahn, Cassidy, and Laval 2004) and, in 2017, Khansari et al. studied the distribution of TH in different lanes (Khansari, Tabibi, and Moghadas Nejad 2017).

Furthermore, the study of headway can help us for a better understanding of the drivers' behavior. There are, of course, a few studies in this regard . Although some researchers, such as Fritzsche and Wiedemann, divided the driving behavior based on multiple variables (Olstam and Tapani 2004), they needed a lot of variables and complex calculations. In other words, these models cannot easily be used in other situations and require some complicated calculations (Aghabayk Eagley 2013).

The following threshold has been the main topic of many papers and it may be estimated by studying TH. The following threshold is defined as the headway span, in which the driver would be affected by her/his leader car (Vogel 2003). In other words, the rear vehicle would enter the following condition by decreasing the headway to a threshold. The following threshold should be determined in the car-following models, which it is usually assumed solely based on the conditions of the recorded data without plausible logic. For example, Amini et al. compared personal car-motorcycle with motorcycle car-following behavior by mounting a camera at the height of 40 m. They selected 100 m as following threshold, only because of the recordable length of the road(Amini et al. 2018).

Some researchers examined the following threshold . Al-Jameel suggested 80 m as the optimum following thresholds by building and examining different GHR (Gazis-Herman-Rothery) car-following models (Al-Jameel 2009). Aycin investigated different thresholds in deceleration situation. It was observed that the follower vehicle was not affected by lead vehicle when the spacing between the following and its leading vehicle is greater than 76 m (Aycin 2001). Herman studied the oscillation between the acceleration and deceleration situations and determined 61 m as following threshold (Chandler, Herman, and Montroll 1958).
Some of the researchers have tried to estimate the following threshold based on TH. Evans and Wasielewski (1983) proposed 2.5 sec TH as the upper limit for interacting vehicles, based on a

mathematical model of headway distributions. They postulated that the distribution of following vehicle headways is Poison, while free vehicles have headways that are exponentially distributed. Vogel(Vogel 2002) examined different correlation values between speed and headway at an intersection in Sweden and found 6 sec as the threshold. Loulizi et al. considered car-following condition as the minimum of two criteria: 100 m of headway and 4 sec of TH (Loulizi, Bichiou, and Rakha 2019). Chenyi et al. assumed 1.7 sec as the car-following threshold by dividing TH dataset into several subsets and measuring them by the GHR model(Chen et al. 2010). By modeling lane changing and acceleration, Ahmed (Ahmed 1999) divided TH into three intervals. He suggested that the following vehicle is surely inside and outside car-following behavior when TH is smaller than 0.5 sec and larger than 6 sec, respectively. Between these values, he assigned a truncated normal distribution to the probability of car-following behavior. It should be noted that the above result is not due to the direct analysis of TH, but he proposed it based on his lane changing model. Toledo (Toledo, Koutsopoulos, and Ben-Akiva 2007) assumed same procedure for defining TH threshold, too. He found 1 and 4 sec as lower and upper bound of following span, respectively.

There are some other researchers that directed their attention to the psychological aspect of TH threshold. Subjective impressions of task difficulty, risk, effort, and comfort are key variables of these kind of studies. Lewis-Evans et al.(Lewis-Evans, De Waard, and Brookhuis 2010) recruited 40 participants to drive behind a vehicle traveling at 50 km/h at predefined THs. THs ranged from 0.5 to 4.0 sec at 0.5 sec intervals. After each drive, participants filled a questionnaire for rating of experienced risk, task difficulty, effort and comfort in 7-point Likert scale. They showed that 2.0 sec can be considered as TH threshold as the all ratings increased tangibly. Siebert et al. (Siebert et al. 2017) conducted an investigation on TH threshold by applying methods of limits of ascending and descending stimuli (Gouy et al. 2012). Their experiment procedure was approximately same as Lewis-Evans' study(Lewis-Evans, De Waard, and Brookhuis 2010). Participants drove at speeds of 50, 100, and 150 km/h in a city, rural, and highway setting. Their purpose was to investigate the correlation of THs in self-driving and driving with an adaptive cruise control. TH varied between 0.5 and 4.0 sec at 0.1 intervals. They showed that the mean TH threshold lies between 1.5 and 2.0 sec. Almost all psychological studies of TH involve individual experiments by simulator. So, the quantity of gathered data is so much less than that of the filming traffic flow.

As mentioned above, various targets can be achieved by studying TH in different aspects, which have been investigated in different articles separately. This paper aims to study driving behavior with a unified and continuous approach by dividing TH into intervals. Also, the previous researchers have studied the lane-based flow which isn't applicable to developing countries, such as Iran, where the non-lane-based driving behavior is common (Ramezani Khansari, Tabibi, and Moghadas Nejad 2018).

There is a fundamental assumption in car-following and TH research in developing countries that is the drivers observe lane-based behavior. But there are many other investigations about non-lane-based car-following behavior, in which TH was defined by considering significant lateral distance(Das, Maurya, and Budhkar 2019; Jin et al. 2012). This behavior is prominent in many developing and underdeveloped countries. The non-lane-based behavior is more complicated than the lane-based (Gunay 2009; 2007).

The main purpose of this paper is to recognize the following behavior of the driver based on TH in order to assign appropriate behavior to each interval or segment of TH. Hence, each specific following behavior can be studied more accurate and in detail by its distinguished data. In previous studies, the TH was investigate in order to understand a particular following behavior, but here instead of a particular condition, the entire range of TH is studied. Also, most of them are in the lane-based traffic flow, while here a flow with non-lane-based behavior is discussed.

In this paper, a threshold for lateral distance is proposed as a criterion to distinguish between lane-based and non-lane-based behavior and it's examined. which is not clear in previous researches(Jin et al. 2012). And, each behavior is compared to other to understand the differences. The paper is concluded by estimating following threshold, which is so important in developing car-following models, by same method as other behavior.

In this research, TH is studied in a step by step method from smallest to largest values by considering the effect of lateral distance. The second section is assigned to the method of collecting data by using filming and image processing algorithms, in which the trajectory of vehicles can be calculated and extracted. The third section categorizes the following behavior, and lane-based and non-lane-based behavior is studied in sections fourth and fifth, respectively. The following threshold is investigated in sixth section. Finally, sections seven and eight are discussion and conclusion.

METHODOLOGICAL FRAMEWORK

In this section the data collection and analysis is presented. Figure 1 depicts the steps of studying TH and its results briefly to clarify the analysis procedure. First, the non-lane-based and lane-based driving behavior and their details are studied, then the following threshold is discussed.

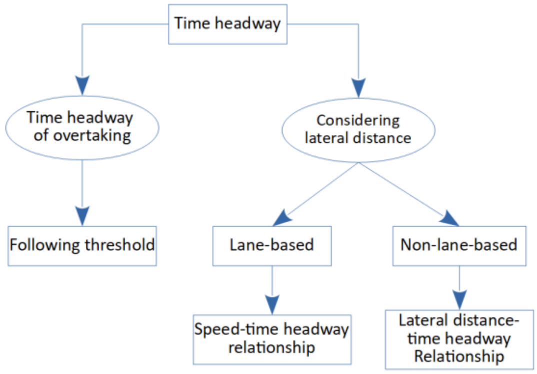

FIGURE 1. Procedure of studying TH

DATA COLLECTION PROCESS

Data were gathered from films rural freeway in Iran, Tehran-Karaj freeway. The length of the freeway, which had the acceptable quality for image processing, was roughly 100 m (figure 2). The movies of traffic flow were obtained from one of the cameras in the archive of Bureau of Rural Road and Transportation. The camera was installed at the height of 20 m from the road and in the median of the freeway, and its resolution was 1280*720(HD 720). Movies were analyzed at intervals of 0.1 sec. During 300 min, 2580 vehicles were selected, and 92,278 rows of data were extracted. The maximum and the minimum speeds were 127 and 61 km/h. The average speed and TH of vehicles were about 97 km/h and 0.9 sec, respectively. The maximum recorded TH was 3.24 sec. By considering non-lane-based or no-coaxial driving definition, which is defined in further sections, 35% and 65% of vehicles were categorized as non-lane-based and lane-based, respectively.

FIGURE 2. Snapshot of recorded movies

Because of the quality and angle of the camera, it was not possible to use automated image processing methods such as motion detection. Thus, a semi-automatic method was applied and a specific program for semi-automated analysis was developed by Python programming language and OpenCV library. In this program, the operator or user selects the vehicles by drawing rectangles around them, and the computer just tracks. Random checks and comparisons with manual results proved that the semi-automated method was significantly more accurate than the automated one. It should be considered that the software was very time-consuming and needed high processing sources. An initial testing indicated it requires approximately 10 person per minutes to process one minute of video data. The figure below depicts a screenshot of program interface in Linux In this method, the image processing process is divided into two sections: vehicle detection and vehicle tracking. The detection step was done entirely manually by an operator to reduce errors. In the second step, the software uses the Kernelized Correlation Filter algorithm to track selected vehicles. The combination of these two methods led the developed software to be more precise. Trajectories of vehicles were smoothed by the symmetric Exponential Moving Average filter(sEMA) proposed by Thiemann et al.(Thiemann, Treiber, and Kesting 2008). By considering the image resolution, the average accuracy of the approach, across all area, was about 20 and 230 cm for the lateral and longitudinal distance results. Figure 3 shows a screenshot of developed program. It should mentioned the image processing only provide trajectory data in a specific rate and other variables and parameters were calculated by using mathematic and geometric calculations.

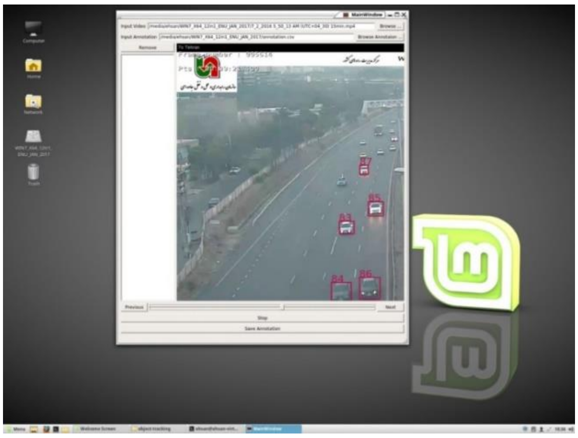

FIGURE 3. Screenshot of the semi-automated program interface

According to the movie's specifications, TH or longitudinal distance and lateral distance variables were used as depicted in figure 4. Considering that this research only focuses on the personal car-personal car situations and the dimensions of personal cars are approximately the same, the aforementioned variables can calculate other variables.

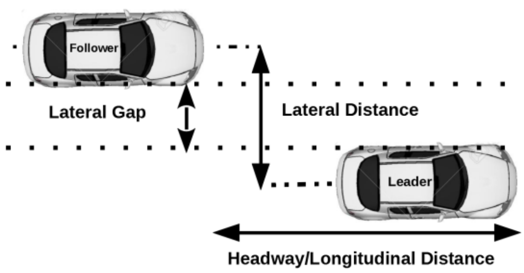

FIGURE 4. Lateral and longitudinal distances

DEFINING LANE-BASED AND NON-LANE-BASED DRIVING

In this study, the car-following behavior has been divided into three categories based on the lateral distance, including the non-coaxial, coaxial, and free driving (out of the following).

1) Coaxial following: This type of following is observed when the lateral offset of a follower and a lead vehicle is less than a certain amount, thus lateral distance does not affect following behavior. It can correspond to lane-based driving behavior. Transverse distance of less than 50 cm was considered as the coaxial car-following behavior. 50 cm was assumed as the driver's error to follow the leader vehicle path exactly. In other words, if the lateral distance of two vehicles was less than 50 cm, it was accepted that the follower vehicle is trying to drive behind the front vehicle but with some errors.

This value was obtained according to data from one of the US highways. Although the US drivers adhere to lane-based driving, they are expected to not to drive exactly on the behind of their leader cars and have some lateral distance. Figure 5 shows that the lateral distance of more than 85% of the drivers was less than 0.5 m. Therefore, it can be said that if Iranian drivers intend to observe lane-based or axial behavior, they are allowed to have about 0.5 m tolerance for lateral distance.

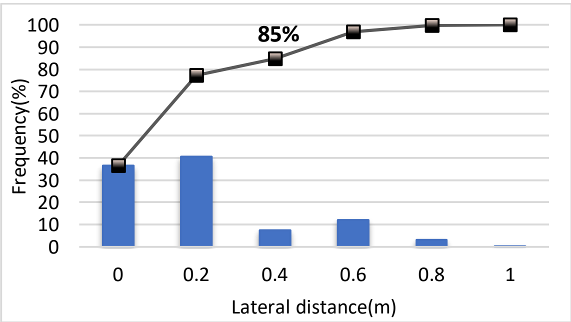

FIGURE 5. Probability and cumulative distribution of lateral distance of a sample of US drivers

2) Non-coaxial following: it means the driver has considerable lateral offset and she/he consider this lateral distance during fallowing. It can correspond to non-lane-based driving behavior. By considering 170 cm as the maximum width (160 cm on average) of the most personal cars in Iran, and 50cm as the safe lateral gap between the cars, the maximum lateral distance was calculated about 220 cm for the car-following behavior. Vehicles whose lateral distances were between 50 and 220 cm, were considered as the non-coaxial car-following. The congested flow was investigated to estimate the safe lateral distance. Lateral distance in the congested state, almost stop-and-go condition, was around 90 cm, indicating that this number is the minimum safe lateral distance (Fig.6)

FIGURE 6. Congested flow of Tehran-Karaj highway

A study in India, where the non-lane-based behavior is widespread, showed that the minimum of the lateral gap would be 100 cm(Budhkar and Maurya 2017). Thus, to ensure the existence of the following behavior, it was considered 50cm. In other words, it can be said that if a follower vehicle considers 100 cm as the safe lateral gap at lower speeds, she/he is confidently in the following behavior at lower distances.

3) Out of the following (free driving): lateral distances greater than 220 cm would indicate that the leader hardly affects its follower. This article only deals with the following states, and the latter case is excluded. The categorization above is summarized as follows in figure 7.

FIGURE 7. Categorizes of following behavior based on lateral distance

The non-coaxial and coaxial car-following behavior correspond to the non-lane-based and lane-based driving behavior, respectively. Hence, these two standard terms are used in further sections. It is worth mentioning again that the following behavior means the rear vehicle is under the effect of the vehicle in front, and thus they can be called follower and leader vehicle, respectively. Beside above conditions for the lateral distance, the two vehicles should have some other condition to consider as following including a) The speed difference was less than 5 km/h, b) both of them had no significant lateral movement c) both pervious conditions should be observed for all recorded data of the two vehicles. By distinguishing non-lane-based from lane-based following behavior, they are studied in the next sections in detail.

2.3. LANE-BASED BEHAVIOR

Iranian drivers' headways are compared with a developed country such as the US (Aghabayk et al. 2014) in figure 8. By using simple calculation, it can be seen that the average TH of American and Iranian drivers are about 2.2 and 0.9 sec, respectively. The points in figure 8 represent the average data for 5 km/h intervals, and each point includes more than 1000 rows of data.

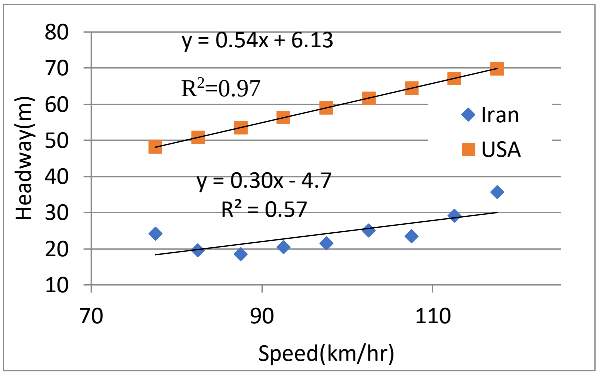

FIGURE 8. Comparison of Iranian and American drivers` headway

Figure 9 shows that the parabolic equation is more suitable than linear for TH in Iran, which is different from the US. It should be mentioned that the outlier points were omitted by the box plot method, as shown in figure 10.

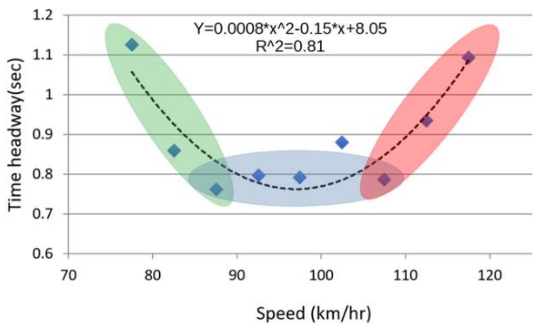

FIGURE 9. Relationship between speed and TH

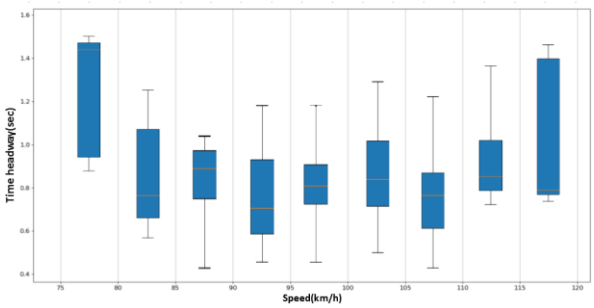

FIGURE 10. Distribution of TH in lane-based driving behavior

It was expected to see a uniform relationship between time headway and speed based on previous researches (Aghabayk Eagley 2013), unlike the figure 9. In general, the diagram can be divided into three parts: the descending (green) section, the almost constant (blue) section and the ascending (red) section. These parts could be interpreted based on the frequency of overtaking maneuvers and average speed (AV) of the flow, which is roughly 95 km/h, as follows:

Speed< AV (green section): As the drivers in this section drove slower than AV, it was expected that other vehicles overtook them and they scarcely overtook the others. As the frequency of overtaking decreases, the probability of occurrence short or close TH may decreases. On the other hand, it may be considered that these drivers drove slower than AV because they were more cautious. This two reasons, more caution and less overtaking maneuvers may account for the increase in the average of TH for drivers at the speeds less than AV. Speed≈ AV (blue section): Smaller THs can be seen around AV. It means that by approaching AV, TH would decrease. This can be due to the increasing of overtaking maneuvers. Speed> AV (red section): In the third part of the diagram, the TH increases again. By closing on the speed limit (120 km/h), the tendency to overtake would decrease as the risk of being fined by the speed camera. Moreover, the drivers can reach this speed (around maximum) when the density is so low, thus they hardly have to overtake. Hence, the decrease in the number of overtakes would lead to increase TH. It should be mentioned that it was seen that Iranian drivers decrease their distance during overtaking so as to warn the preceding vehicle to let them pass.

It can be expected that the TH should be independent of speed, as manuals and papers suggested 2.0 sec as the safe TH for any speed(Vogel 2003). But it was shown that the TH can vary based on the difference between the speed of subject vehicles and AV, and also the frequency of overtaking maneuver.

NON-LANE-BASED BEHAVIOR

Figure 11 shows the relationship between TH and lateral distance in non-lane-based behavior. Lateral distance values were averaged over 50 cm intervals for better fitting. There are almost 1000 rows of data at each point. By reducing TH, lateral distance has increased, which is expected.

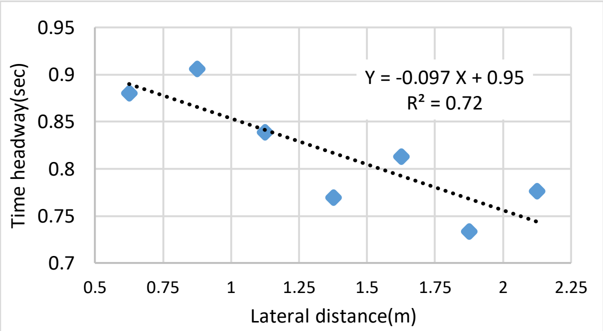

FIGURE 11. The relationship between lateral distance and TH in non-lane-based car-following

Figure 11 shows that the lateral distance in non-lane-based is generally less than lane-based. Table 1 shows the result of a two-sample t-test between the TH of lane-base and non-lane-based. It can be inferred that the behavior of a driver would be changed from lane-based to non-lane-based by reducing TH and closing the vehicle in front.

TABLE 1. Comparison between the TH of lane-based and non-lane-based driving

	Lane based	Non-lane-based
Mean	0.97	0.82
Variance	0.01	0.003
t Stat	11.79	
P(T<=t) one-tail	< 0.001	
t Critical one-tail	1.66	
P(T<=t) two-tail	< 0.001	
t Critical two-tail	1.98	
Result	Lane based > Non-lane-based	

FOLLOWING THRESHOLD

Previous sections demonstrated that the TH of lane-based behavior is larger than non-lane-based. Now, this question arises whether a maximum threshold can be estimated for the end of the following behavior and follower isn't under the effect of a leader. For this purpose, the TH in which derivers change their lane to overtake was examined, as the driver can avoid the risk and stress of the following by overtaking. Thus, this point was named as the start of free driving, because the driver can select between entering following or overtaking. Figure 12 depicts the trajectory points of the vehicles that have changed their lanes because of overtaking. Each point in the figure below shows the relative position of the rear vehicle (compared to the preceding vehicle) during overtaking.

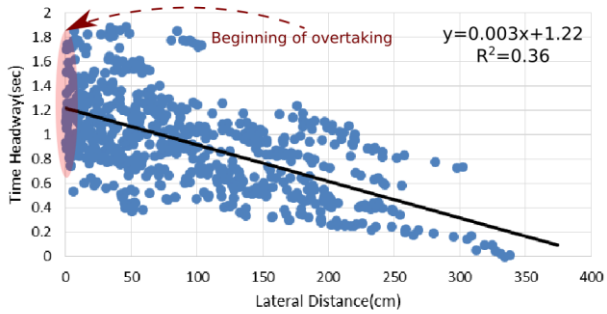

FIGURE 12. Relationship between lateral distance and TH within overtaking

The points on the vertical axis, in which lateral distance is zero, represents THs at the beginning of the overtaking maneuver. The distribution of these points (about 450 points) was shown in figure 13. The 3-parameter Weibull distribution is used for TH at the beginning of the overtaking, because simultaneously it has the advantages of considering lower bound and a shape very similar to the log-normal distribution, which is the most accepted among all the distributions for TH(Jang et al. 2011; Sadeghhosseini 2003; Bham' and Ancha 2006).

These are scattered from 1 to 1.75 sec, and the average is roughly 1.25 sec. As abovementioned, these THs were considered as the threshold of the following behavior.

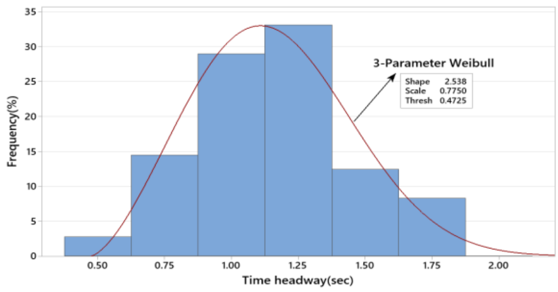

FIGURE 13. Distribution of the TH at the beginning of the overtaking

Table 2 shows that the average TH of lane-based following is less than that of overtaking, based on the two-sample T-test. In other words, overtaking TH can be called the upper limit of lane-based behavior because it is one step beyond the TH of lane-based following behavior.

TABLE 2. Comparison between the TH of overtaking and lane-based driving

	Overtaking TH	Lane based
Mean	1.26	0.97
Variance	0.08	0.01
t Stat	-7.14	

P(T<=t) one-tail	< 0.001
t Critical one-tail	1.65
P(T<=t) two-tail	< 0.001
t Critical two-tail	1.97
Result	Overtaking TH > Lane based

The TH in which the drivers start to overtake was considered. The data were between 0.5 and 2 seconds, with an average of 1.25 sec. The average TH of lane-based following was less than overtaking, and it shows the drivers who couldn't or didn't want to overtake would enter the following behavior. In other words, overtaking would be a boundary between following and free driving. In order to find the start point of free driving behavior, the probability distribution function of overtaking THs was estimated.

3-parameter Weibull distribution fitted well, as Khansari et al.(Khansari, Tabibi, and Moghadas Nejad 2017) showed that this distribution is suitable for TH. By calculating 0.999 area of the cumulative distribution function (eq.1) of the estimated 3-parameter Weibull, the maximum TH for overtaking was 2.5sec.

$$F_x(x) = 1 - e^{-\left(\frac{x-\mu}{\beta}\right)^{\alpha}} = 0.999 \qquad \text{Eq.1}$$

α= shape parameter
β= scale parameter
μ= location parameter

DISCUSSION

By combining all parts of this research, it has been tried to classify driving behavior based on TH. TH used instead of headway because it is nearly independent of speed, and it helps us to show and visualize results without considering speed. The paper aims to explain different intervals of TH as it increases from smallest to largest values. In this paper it was tried study lane-based driving, non-lane-based driving behavior, and following threshold in a continuous and unified approach, which were studied in separate papers without considering each other.

The smallest TH interval would be non-lane-based following behavior. The data in this part were almost scattered over 0.7-0.9 sec, with an average of 0.81 sec. As this TH is so small and dangerous, the driver adopted lateral distance, which led to seeing a linear relationship between TH and lateral distance. This matter can show the reason for non-lane-based driving behavior. In other words, the lateral distance in the non-lane-based following would be a result of closely following, and the frequency of non-lane-based driving behavior may be diminished by forcing drivers to have larger headways. It can be seen that in the lane-based state, the TH is larger.

The next TH interval would be lane-based car-following behavior, in which data were almost distributed among 0.8-1.2 sec with the mean of 0.97 sec. The fitted curve on TH-speed showed that it could be divided into three parts based on the average speed. The average speed could influence the number of the tendency to overtake, and drivers tend to smaller TH during overtaking. Thus the lowest THs were around the average speed.

It is worth mentioning that while the reduction of headway within overtaking was observed in two-lane undivided roads of Iran(Jokar 2012) and other countries(Hegeman, Hoogendoorn, and Brookhuis 2004), it can be seen here in a freeway in which there is no peril of head-on crashes. As demonstrated, the drivers would change their behavior from non-lane-based to lane-based by increasing TH, then it was studied to what extent the lane-based behavior would extend.

It was shown that the endpoint of overtaking behavior and the start of free driving. Although there are cars that have overtaken at higher distances and not registered in our data, the goal was to find the most critical or minimum TH. In most previous studies, the threshold of free driving was stated in terms of headway (length), which couldn't be correct due to the effect of speed. Here, if desired to be expressed in terms of length, the threshold would be 85 and 34 m for 120 and 50 km/h, respectively. Figure 14 shows all the above descriptions briefly. As headway less than 0.7 sec was rare, this part of data was assumed undesirable or unsafe interval.

FIGURE 14. Different driving behavior based on TH

Regression with different goodness of fit was used to analyze some diagrams in this research. In statistical texts, the fitness index of higher than 0.7 has been considered acceptable. In traffic studies, lower values can be accepted. Traffic studies are a subset of social science, and therefore the fitness index between 0.3 and 0.6 can be approved (Papacostas and Prevedouros 2015).

CONCLUSION

Although the concept of TH is straightforward, and it was the major or minor object of so many researches, it still has the potential to study from different aspects. Driving behavior, TH in a non-lane-based flow in Iran were studied in this research. In this paper driving behavior, speed-TH relationship and following threshold by using only headway were investigated. Also, they studied lane-based flow which is different from developing countries, such as

Iran, where the non-lane-based driving behavior is typical. The secondary result of this paper was introducing a procedure for studying TH, by which the TH can be divided into parts based on the changes in driving behavior. The main goal was considering and combining lateral distance and time headway (or headway), so the car-following TH would be different in lane-based and non-lane-based conditions. TH of non-lane-based behavior was less than lane-based. Short THs would force drivers to apply lateral distance or vice versa. The time headway was used in order to draw results almost independent of the speed. The Results showed that Overtaking TH can be a good criterion for determining the following threshold. Different driving behaviors based on TH (averagely) in a non-lane-based flow can be Unsafe (0-0.7 sec), non-lane-based car-following (0.9 sec), lane-based car-following (1.0 sec), overtaking TH (1.3 sec), and free driving (larger than 2.5 sec).

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