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Studying Non-coaxiality in Non-lane-based Car-following Behavior

Ehsan Ramezani Khansari [a], Masoud Tabibi [b*], Fereidoon Moghadas Nejad [c]

[a] *PhD. Candidate of Transportation Engineering, Amirkabir University of Technology, Tehran, Iran.*

[b] *Assistant Professor of Transportation Engineering, Amirkabir University of Technology, Tehran, Iran.*

[c] *Associate Professor of Transportation Engineering, Amirkabir University of Technology, Tehran, Iran.*

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Abstract

In this paper, in order to study non-lane-based car-following, the non-coaxiality concept is defined, where there is a significant lateral difference between the leader and follower vehicle. Two main reasons for non-coaxiality were addressed by drivers in the interview: providing more visible distances beyond leader vehicle and increasing the possibility of escaping in sudden brakes to avoid rear-end collision. Results showed that non-lane-based behavior was due to the effect of the existence of other cars in the traffic flow. By reducing speed or increasing density, vehicles more affect each other. But this trend will continue up until vehicles fill the free spaces. In other words, vehicles make others stick to the leader's path in high-density flow. Studying the relationship between lateral distance and time headway demonstrated that time headway threshold for initiation of car-following behavior in Iranian drivers can be approximately 2 seconds. In this study, Overtaking was defined as a part or continuation of the non-lane-based driving behavior. For overtaking on the left, steering angle, the final lateral distance and the lateral speed difference between the follower and leader were 33%, 28% and 15% less than overtaking on the right.

Keywords: Non-Lane-Based Behavior; Car-Following; Traffic Engineering; Overtaking Behavior.

1. Introduction

Non-lane-based driving behavior can be seen in developing countries, such as Iran, extensively. This behavior can interrupt the traffic flow. This behavior may be adjusted by knowing its nature and details. Non-lane-based driving behavior leads the drivers adjust their headway based on speed and lateral distance, simultaneously. Non-lane-based driving behavior is important by considering traffic flow and safety aspects. This behavior reduces the predictability of vehicles for other drivers, moreover it prevent the traffic flow to provide enough spaces for escaping in dangerous conditions. From traffic flow point of view, it can affect the flow characteristics such as density and volume.

In this paper, non-lane-based driving behavior is divided into two categories based on the direction of lateral distance. Consequently, overtaking behavior was studied as a transient non-lane-based maneuver. Even though there are many researches about modeling non-lane-based behavior, here it has been tried to investigate why, where and how it happens.

Firstly, in this paper the relationship between the frequency of happening non-lane-based car-following and macroscopic characteristics of traffic flow will be estimated. Then, microscopic data will be studied to know how it happens. Consequently, it can illuminate whether the non-lane-based behavior is an intrinsic behavior of Iranian drivers. In other words, it shows that obeying rules and orders is not important for the drivers or non-lane-based car-following is due to environmental conditions and drivers' personal experiences.

* Corresponding author: masuod.tabibi@gmail.com

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Next section is assigned to literature review about non-lane-based driving behavior studies. Section three describes the characteristics of data. Sections four and five try to examine occurrence frequency and details of non-lane-based car-following behavior. Some drivers were interviewed in order to research on rationale of this behavior. The procedure and results of interviews are presented in section six. Finally, sections seven and eight are devoted to discussion and conclusion.

2. Literature Review

The lane-based car-following has been studied in many researches. The behavior in which movement of the vehicles is according to markings on the roadbed [1-4]. In developing countries, such as Iran, the non-lane-based behavior is observed frequently in traffic flow. In many articles, the effects of off-center driving have been investigated on car-following behavior.

Gunay studied non-lane-based behavior in several researches. He demonstrated that the distribution of lateral position data in developing countries, such as Turkey, is different from developed countries in two aspects: a) drivers have trend to use the median lane. As density and volume increase, they gradually use other two lanes(middle and shoulder lanes), b) the distribution of lateral position within a lane is untidy and out of normal distribution[5-6]. He delved into lateral position data in developed countries, Germany and England. He found out that the distribution of data was normal[7]. He proposed a car-following model regarding lateral discomfort. The lateral discomfort was defined due to lateral friction between vehicles. His model was a two-dimensional model, that it simultaneously considered longitudinal and lateral distance instead of only longitudinal distance [8]. He had studied the proposed model by considering the effect of two or three isolated cars. In another research, he evaluated his previous model by using data from a multilane roadway with many vehicles which could interact with each other during lane change maneuver. The results of simulation and comparison with practical data demonstrated that the proposed model was also applicable to multilane mode [9].

Gunay and Woodward[10] examined the lateral position in horizontal curves in Ireland. They found that the drivers tended to the convex side and they almost showed the non-lane-based behavior. This tendency increased with radius reduction. They also concluded that this was due to lesser skid resistance, faded or lack of road markings. Jin et al. [11] improved the optimal speed model by considering lateral separation effect. They found that this improvement in simulation led to avoid unrealistic traffic jams. There are other articles that investigated the effects of drivers' non-lane-based behavior on the car following behavior [12-14].

Also, the non-lane-based behavior of motorcycles has been measured. Cho and Wu [15] studied the non-lane-based behavior of motorcycles. They found that lateral position of a motorcycle can be estimated by surrounding cars. They assigned weights to the vehicles by considering their longitudinal position compared to motorcycles. Nguyen et al. [16] studied the non-lane-based behavior of motorcycle in congested traffic. They introduced new features such as the conditions to choose the leader car, the acceleration and deceleration parameters. Their results emphasized the fact that more conflicts occur at higher densities, that is due to the possibility of sudden braking. Amini et al. worked on the difference between car-car and car-motorcycle situations. They found that drivers behind motorcycles were more cautious than behind car. They interpreted that it is due to lower predictability of the motorcycle behavior and maneuver [17]. Topolsek and Ojertersek studied the difference between car driving and motorcycle riding behavior of same person by using standard driving behavior questionnaire and structural equation modeling. They found that there is no significant difference [18]. Aghabayk et al. tried to calibrate Weidman’s car-following model for heavy vehicles. They found there is a significant difference between vehicles classes [19]. In another study Chen et al. demonstrated that passenger car-following behavior is different in the presence of heavy vehicles [20]. Time headway of vehicles is affected not only by vehicles class but also the condition of traffic flow.

Also, there are some other researchers that investigated the non-lane-based driving behavior in heterogeneous traffic flow. They demonstrated that the conventional car-following models have some limitation to mimic practical data in developing countries and they must be refined [21, 22].

The goal of almost all researches was to model the non-lane-based behavior, but the origin and cause of such behavior in traffic flow were rarely studied. In recent years, although the government and police in Iran have made extensive efforts to encourage drivers to drive in the lane or stay in lane, they still don`t obey.

3. Data Collection

To collect data, we utilized a camera overlooking the traffic flow of Tehran-Karaj freeway in Iran. The camera was installed at a height of about 20 meters from the road surface and in the median of the roadway. The practical scope of camera was roughly 100 meters which covering the entire width of the road (Figure 1).

The selected section has four main lanes and a paved shoulder. It is far enough from ramps, loops horizontal and vertical curves, so the traffic flow is in steady and normal state and disturbance is infrequent. Data were recorded during daylight hours. Data were embraced almost all levels of service, except stop-and-go condition. The traffic flow was almost comprised of buses and personal cars.

Figure 1. Area covered by the traffic camera and location of the case study

By considering range of speed of the freeway, which is 70 to 120 km/h, and 100 m scope for the camera, the maximum recorded time headway was calculated as shown in Table 1 by Equation 1.

$$\text{Time headway(sec)}=100(\text{m}) / \text{Speed(m/sec)} \quad (1)$$

Table 1. Maximum recordable time headway (sec)

Speed km/h	Maximum recordable time headway (sec)
70	5.1
80	4.5
90	4
100	3.6
110	3.3
120	3

Equation 1 calculates time headway of vehicles by the means of recorded speed and headway. Maximum recordable headway is considered to be equal to camera scope (100 m). Hence, maximum recordable time headway could be calculated by using Equation 1.

It should be noted that the calculated time headway has crucial role in this investigation. In other words, if this factor is less than maximum time headway for Iranian car-following behavior, the obtained data cannot describe driver's behavior in larger time headways (since they are not recorded in field data). Consequently, the developed models cannot be generalized for all time headways. The prevalence of rear-end collision in Iranian roads indicates the fact that Iranian drivers often do not adhere to appropriate and recommended headway, and use less than 2 seconds for car-following. On the other hand, in a study conducted by Khansari et al. in 2016 in Iran, they showed that about 85% and 70% of Iranian drivers accept time headway less than 3 seconds in congested and uncongested conditions [23]. At least the data included 3 sec time headway for all speeds, as shown in Table 1, which makes sure almost all following cars were recordable. Thus, the maximum recordable time headway is adequate to study car-following behavior in Iran.

It is worth mentioning, for uniformity of results, maximum of 120 km/h was considered as acceptable speed and cars with higher speed were deleted. This was because the aggressive driver's data may cause confusion in data and results. The recording duration was about 300 minutes. It was attempted to include traffic flow with various density. The data collection was only comprised of personal car (PC) behind the PC, and the rest of the situations (Such as bus-bus, car PC-bus, bus-PC, etc.) were ignored. 1125 cars were recorded. The videos were processed at intervals of 0.1 seconds, thus 8962 row of data were extracted. Figures 2 and 3 show the distribution of speeds and time headway in recorded data.

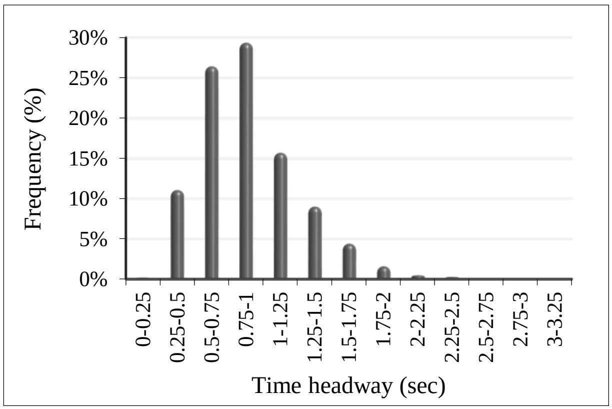


Figure 2. Distribution of speed for recorded data

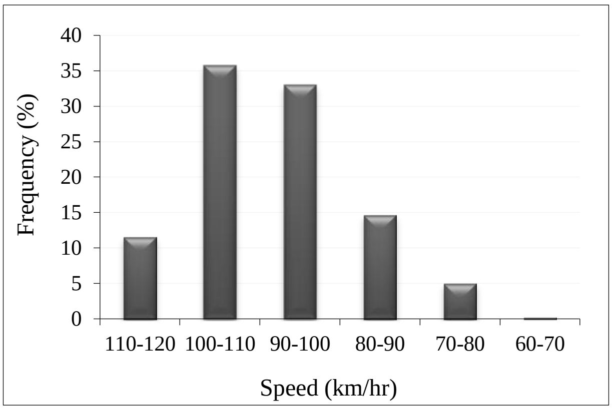


Figure 3. Distribution of time headway for recorded data

The motion detection method was examined to extract data from videos automatically. The vehicles in the films sometimes overlapped each other, because of the camera angle and high density of traffic flow. Therefore the algorithm couldn`t detect and track vehicle precisely. Then a specific program for semi-automated analysis was developed by Python programming language and Open CV 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. The figure below depicts a screenshot of program interface (Figure 4).

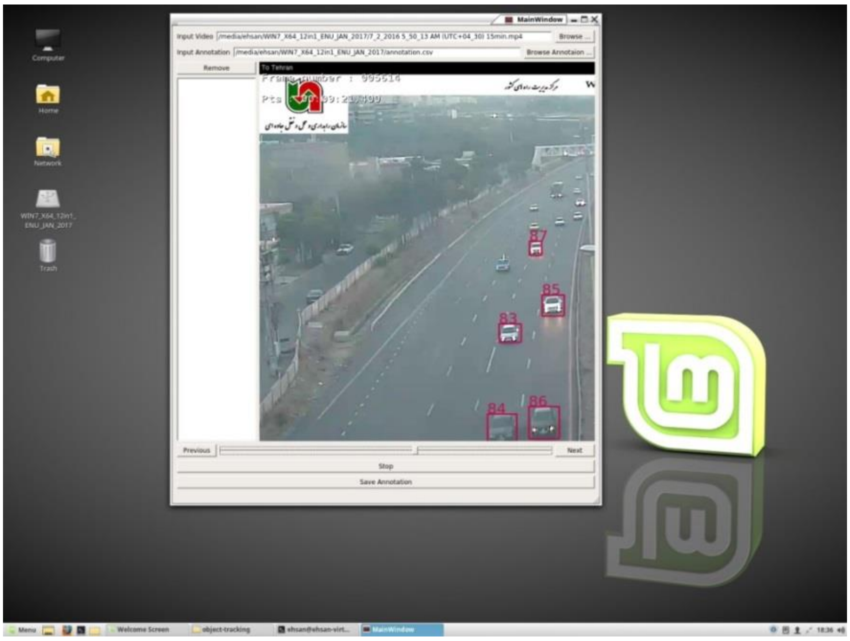


Figure 4. Screenshot of the video analyzing program interface

4. Non-Lane-Based Car-Following and Flow Characteristics

Non-lane-based behavior can be due to the presence of other vehicles. This issue requires an analysis of the relationship between the various volumes of traffic flow and the occurrence of the non-lane-based behavior. To extract the percentage of vehicles with non-lane-based behavior in traffic flow passed cars data were collected at 5 minutes intervals and the average speed was calculated. In order to study non-lane-based behavior more precisely, two concepts are defined in this paper: coaxial and non-coaxial car-following. Non-lane-based behavior means that drivers do not consider the markings on the roadbed and only adjust their position to the leader vehicle. Hence, it should be looked for another factor, which drivers determine their lateral position accordingly. The lateral position of the leader vehicle was assumed as the alternative factor. Because drivers always consider the position of their leader vehicles for safety. Thus, driving behavior was divided based on the lateral distance between longitudinal axials of vehicles. In the coaxial situation, the follower is approximately completely behind the leader vehicle. In the non-coaxial situation, a significant part of the follower is out of the leader path and it can be said that there is a projection. Equation 2 and Figure 5 depict the lateral speed definition.

$$\text{Lateral speed} = \frac{\Delta x}{\Delta t} = \frac{\text{Lateral Movement}}{t_2 - t_1} \tag{2}$$

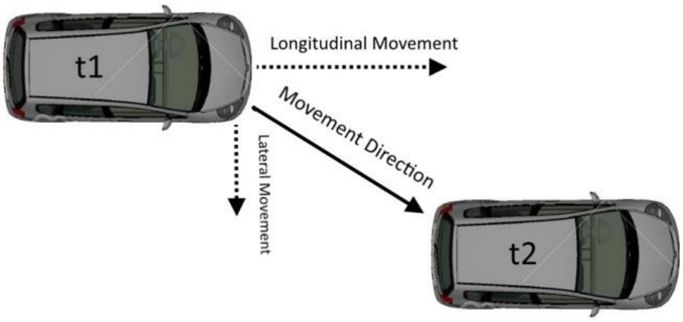


Figure 5. Lateral movement definition

Non-coaxial behavior was defined when the lateral distance between follower and leader vehicles is in range of 50 and 220 centimeters. Considering the width of the conventional vehicle in Iran, that's about 170 cm, and considering an interval of 50 cm as a lateral safety distance between the vehicles, the maximum lateral distance for keeping following the leader vehicle was assumed 220 cm. The lateral distance less than 50 cm was considered as coaxial car-following behavior. So, 50 cm was presumed as a driver's error to exactly adjust driving behind the front vehicle. The lateral distance greater than 220 cm indicates the deliberate behavior of the driver to not follow the leader car (Figure 6). Therefore, the car-following phenomenon has not occurred (Equation 3).

Transverse Distance < 50 cm → Coaxial car-following

50 cm<Transverse Distance < 220 cm → Non-Coaxial car-following (3)

Transverse Distance > 220 cm → Out of car-following behavior

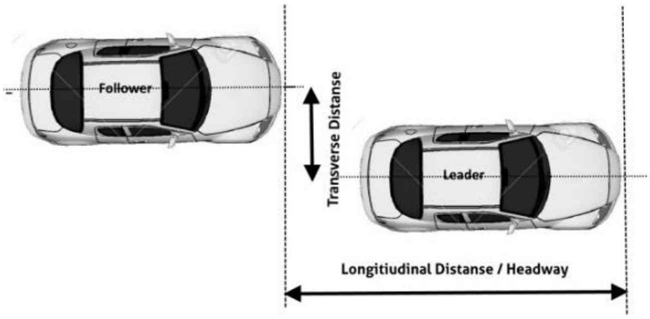


Figure 6. Lateral distance and headway

Although it`s better to use lateral gap instead of lateral distance (center to center), lateral distance was applied in this research because of the following reasons:

1) By considering camera angle and characteristics of recorded videos, the developed program located the center of vehicles better and more precise than their edges. 2) Only PC-PC car-following situation was studied. There is no noticeable difference in dimension between personal cars, especially their width. Besides, in Iran, almost all personal cars are made in two factories and they are so similar in characteristics such as dimension. Thus, lateral gap or lateral distance can be calculated by having the other one. 3) Statistical analysis and modeling were easier and clearer by using lateral distance, because its values are solely positive.

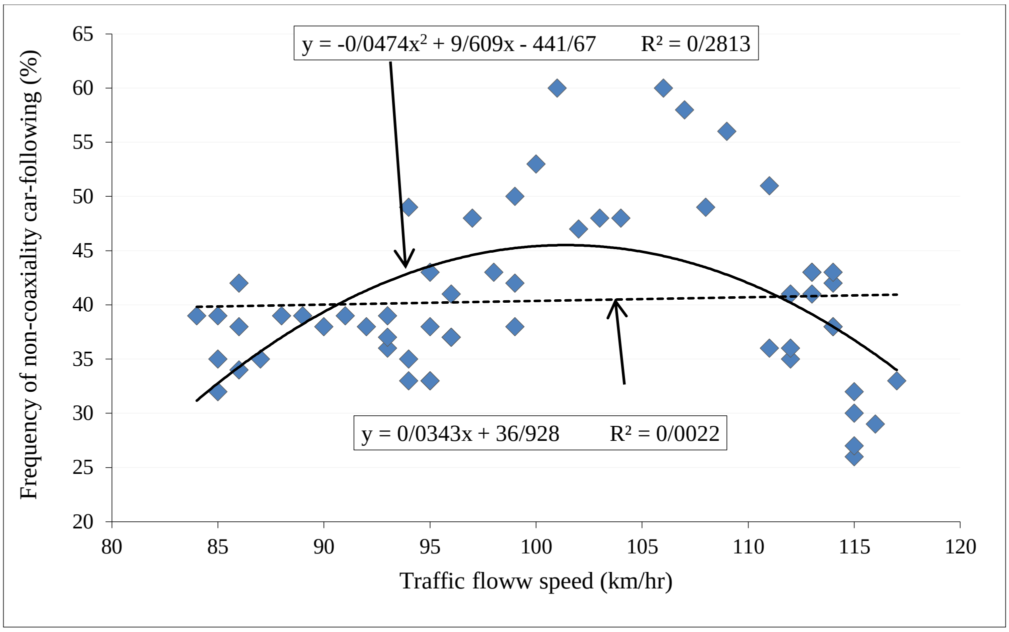


Figure 7. The relationship between speed and non-coaxial car-following behavior

Figure 7 shows the frequency of occurring non-coaxial behavior per all the passing vehicles in traffic flow. Linear and quadric equations were applied to estimate data distribution. By comparing their R-square, it would be found that the quadric was much better. Although the R-square of quadric was roughly 0.3, it can be acceptable for aggregate data. It should be mentioned that the target if this section is not to find best fitting equation rather than equations help to perceive the trend and nature of data. Quadric equation has a peak at point 100 km/hr. In other words, at this speed drivers would tend to utilize non-lane-based behavior more than other speed ranges.

This can be interpreted that when speed is higher (higher level of service), there are fewer vehicles in the traffic flow and the impact of the vehicles on each other would be low. A few numbers of vehicles in the traffic flow can cause long headways, which would reduce the probability of occurring car-following. Figure 8 and 9 depict the different level of service, which indicates that at higher densities or lower speed, the number of happening non-coaxial behavior changes. To draw the chart, data was split into 5 minutes intervals. The average speed and the number of non-coaxial car-followings per sum of the all car-followings were calculated.

Figure 8. Occurrence of Non-coaxial car-following behavior in different densities

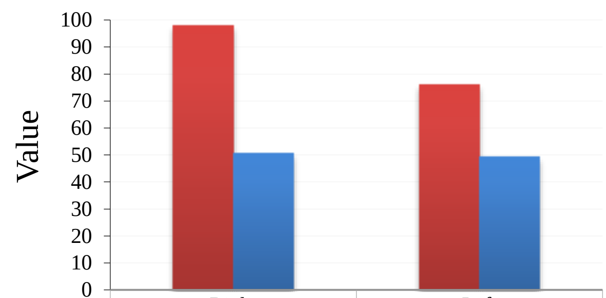
Decrease in flow speed (or increase in flow density) leads to lower percentage of non-coaxial behavior. The continuance of rising flow density gradually makes the vehicles follow each other in a specific path; Hence, the non-coaxial behavior would be diminished (Figure 8). In other words, there would be less lateral space for vehicles to perform non-coaxial behavior. For more explanation, Figure 9 shows a stop-and-go condition where the percentage of vehicles having notable lateral distance was very low.

Figure 9. Reducing non-coaxial behavior in heavily congested traffic flow

5. Statistical Analysis of Non- Lane-Based Behavior Data

5.1. Comparison between Non-Coaxial Behavior to Left and Right Side

Comparison between non-coaxial data to left and the right side shows that percentage of their occurrence would be almost equal (Figure 10). Non-coaxiality to the left means follower car is behind the leader car and its driver tends to the left of herself/himself or to the median of the road. While in the non-coaxiality to the right, driver of the follower car tends to move to her/his right side or road shoulder.



	Right	Left
Lateral distance average (cm)	98	76
Frequency (%)	50.74	49.26

Figure 10. Tendency to right versus the tendency to left

The Figure 10 shows that 51 and 49 percent of drivers have a tendency to non-coaxiality to the left and right side, respectively. In this case, it can be said that, for example, when the car tends to the left and moves at the left side of the leader car; it is very likely that its following car tends to the right side of it. This description is shown in Figure 11.

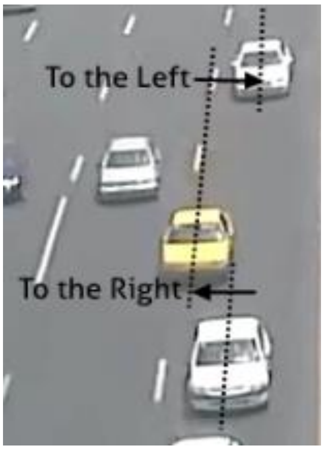


Figure 11. Equality of right and left tendencies

As shown in Figure 11, when the middle vehicle goes to its right, the next car goes to its left side naturally and thus, for each tendency to the right, a tendency would be created to the left. To compare the lateral distances of left and right, the method of T-test two Independent samples was applied with the condition that the standard deviation was unknown and there is an inequality condition for the variances (Table 2).

Table 2. Comparison between the tendency to right and left

Alternative Hypothesis: Non-coaxiality to left< Non-coaxiality to right
Test Statistic, t: -4.4151
Critical t: -1.645109
P-Value: 0.0000
Confidence interval: 95%

Table 2 shows that with more than 95 percent probability, data of the lateral left headway is smaller than the right side. Figure 10 shows that the average lateral distances were 77 and 97 for the left and right, respectively. This demonstrates that drivers accept larger lateral distance to the right rather than to the left side. It can be assumed that the cause of driving with lateral distance, either to the left or right, would be the possibility to observe the front space of the leader car. In other words, drivers tend to observe not only their front car, but they also want to see several cars in front of that. Consequently in any sudden braking or accident; they have the possibility of a safe and proper reaction. The vehicle on the left, compared to the right side, can provide the proper view with a lower movement because the driver's seat is on the left side of the vehicle. Of course, this is a hypothesis and it was discussed here to justify the difference in lateral distances to the right and left side. For a more detailed discussion of the hypothesis and causes of lateral distance, it will be discussed by interviewing with drivers in the later section.

5.2. Compare the Lateral Speed toward the Left and Right Side

Within overtaking drivers show non-lane-based behavior for short time and continually shift their lateral distance. Hence, this section was assigned to car-following behavior in overtaking condition. In non-lane-based behavior, the following car always considers two measures: the lateral distance and the headway. In the overtaking, at different period times, drivers consider appropriate headway and lateral distance toward the leader. Therefore, it would be possible to consider overtaking behavior as a part or continuation of non-lane-based behavior. In order to separate non-lane-based car-following behavior data from overtaking data, data of headway and lateral distance were conditioned to have correlation 0.5 or more.

In order to ensure the intention of overtaking, the data were selected in which the following car would move at least 10km/h faster than the leading car and also, the follower vehicle should have the lateral shift in comparison with the leader car. In other words, if a car did not change its longitudinal headway according to the lateral distance, that is, the car is in the following behavior without overtaking. It is worth mentioning, in previous sections, the data were used in which the following car moves with a constant distance to follow the leader car, and it means overtaking has not occurred. For this purpose, the data were used in which the difference between the longitudinal speed of vehicles was less than 5km/h, and difference of the lateral distance was constant. These two conditions would make it possible to say, with a very high probability, the following car would not be in the overtaking situation. Figure 12 shows the difference of lateral speed in km/h for follower and leader vehicle during overtaking toward the right and left.

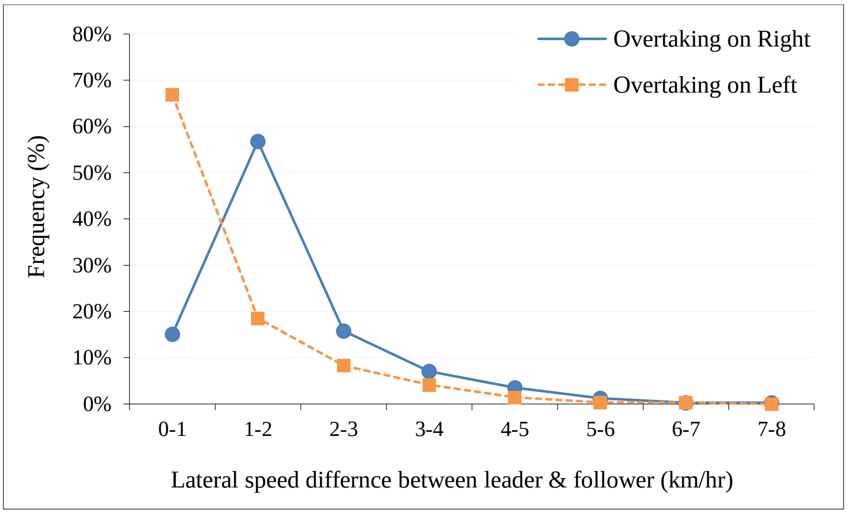


Figure 12. Distribution of lateral speed difference between leader and follower for right and left overtaking

Table 3. Comparison between lateral speed during overtaking on the left and right

Alternative Hypothesis :Overtaking on the Left< Overtaking on the Right
Test Statistic, t: -6.4873
Critical t: -1.645087
P-Value: 0.0000
Confidence interval: 95%

Average lateral speed differences are 1.21 and 1.03 km/h for overtaking on the right and left, respectively. The statistical test showed that drivers who overtake on the right side are 15% faster than left side in terms of lateral speed (Table 3).

5.3. The Relationship between Headway and Lateral Distance in Non-Lane-Based Behavior

In this section, it will be investigated whether there is a meaningful relationship between time headway and lateral distance. Data of overtaking vehicles were used because accessing a wide range of lateral distance and headway data.

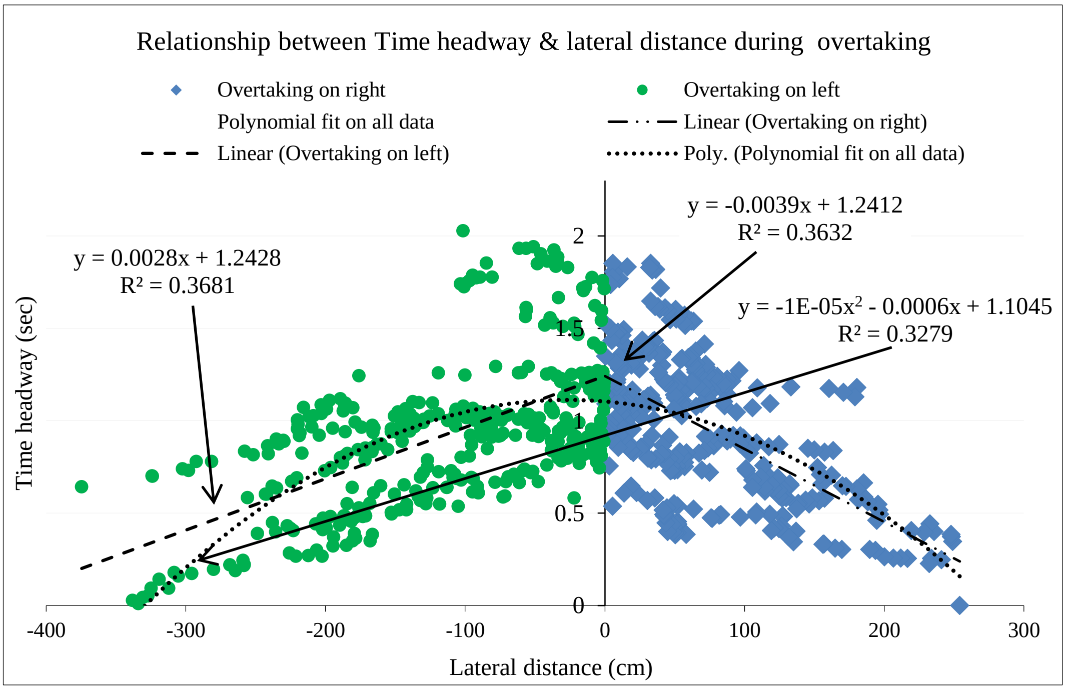


Figure 13. Relationship between lateral distance and time headway

In the above figure, two linear functions were applied for each side of the diagram. And, a quadric function was used to estimate the overall trend of data. Although the quadric data could be enough, those linear functions were drawn to compare overtaking on each direction. As the data were aggregate, the value of R-square was low and between 0.3 and 0.4. The slope of linear equation showed the approximate angle of steering wheel during overtaking. The quadric equation can show the trajectory of vehicle in overtaking maneuver.

Right side (positive) of the chart (Figure 13) represents overtaking on the right (toward road shoulder) and left side (negative) of the chart represents overtaking on the left (toward road median). In order to compare the two sections of the chart, a linear regression was performed on both of them. The regressions proved that drivers that overtake on the right side accepted higher steering angle. The overtaking angle on the right is about 33% less than overtaking on the left. In order to simultaneously study the behavior of left and right overtaking, a quadratic polynomial was fitted on it. The intersections of estimated quadric polynomial and horizontal axes on both side show the lateral distance between leader and follower when they were in same longitudinal position. It means that follower was driving parallel to the leader and beside it. The intersection points of fitted quadratic polynomial curve with horizontal axes demonstrate that lateral clearance at the end of overtaking were 250 and 330 cm for overtaking on the right and left, respectively. As it can be seen, drivers who overtake on the left side had larger and safer lateral distance, roughly 33%, both during and end of overtaking maneuver.

The intersection of the fitted quadratic polynomial with the vertical axis is the time headway, which is about 1.2 sec, but data extension is up to 2 sec. It can be inferred that almost all drivers kept less than 2 sec headway. In other words, by reaching the threshold of 2 sec, drivers start to change the lane. This threshold can be named as the threshold for starting car-following behavior, in which many of drivers try to change their lane rather than following leader vehicle.

Two-sample t-test shows that lateral distance during overtaking on left (114 cm) would be larger than overtaking on right (72 cm) (Table 4).

Table 4. Comparison between lateral distance during overtaking on left and right

Alternative Hypothesis: Lateral distance for Overtaking on the Left> Overtaking on the Right
Test Statistic, t: 7.6326
Critical t: 1.647085
P-Value: 0.0000
Confidence interval: 95%

6. Shooting from Inside of the Car

In order to more careful look at analysis carried out in previous sections, filming inside of the car and interview with the driver was used (Figure 14). The steps in this procedure are as follows:

1) Shooting of driving from inside of the car: traffic flow of Tehran-Qazvin freeway was filmed several times and each video took about 1:45` hours. The total length of the freeway was 145 km. 15 minutes of videos, in which the non-coaxial behavior was very observable, was selected. Two conditions were considered to ensure the occurrence of non-coaxial behavior, a) the driver was supposed to have at least for 3sec visible lateral distance and, b) the driver does not overtake or change the lane during 3 sec.

2) Choosing drivers in order to watch videos: drivers were selected to watch videos. The age range of drivers was between 26 and 52 years old. Among them, 19 and 48 drivers were female and male, respectively. The selected drivers had two characteristics: 1) they must be fully familiar with the freeway path; 2) they must have enough driving experience during 5 years ago. Due to these conditions, selected drivers can be considered as commuters of Tehran-Karaj freeway.

3) The selected drivers watched the videos and they were interviewed: The video was displayed for the selected drivers individually, and then they were interviewed by asking two general questions: 1) Does she/he approve the driving method in the movie? or, did she/he drive the same way? 2) Why did the driver in the movie drive on the left or right side of the leader car, without overtaking or lane changing.

Among the respondents, 11 women and 6 men did not approve this driving style and stated that their driving method was different. It was avoided to ask the second question from them. 9 woman and 42 men considered this method acceptable and, therefore interviews continued with them. It showed that about 88% and 42% of interviewed man and women, respectively, accepted non-coaxial driving behavior as logical driving behavior. Although there were a lot of differences between women's and men's opinions in the first question, in the second part, the answers were almost the same. In response to the second question, drivers considered two factors as the main cause of this behavior, which included having a better visibility over cars and traffic flow further than leader car and avoiding of crashing into leader car in sudden breaking.

Figure 14. Internal recording non-lane-based behavior

7. Discussion and Conclusion

In this study, it was attempted to work on the non-lane-based behavior of Iranian drivers by collecting data in two ways: external recording, shooting traffic flow, and internal recording (inside of the car filming and interview with drivers). Given the traffic conditions, the speed range of data was between 70 and 120 km/h. It should be noted that, when speed is lower than 70 km/h, congested flow traffic may occur and the general condition of the traffic flow would be different. In this situation the turbulence is very probable, thus data of less than 70 km/h were not recorded.

Non-coaxial behavior was divided into two categories: the tendency of the follower vehicle toward right and left. Data were analyzed by using statistical methods. Statistical results demonstrated that vehicles with tendency to the left observed significantly smaller lateral distance in comparison to vehicles that tend to the right. It is necessary to mention that the lateral distance here means the distance between the centers of follower and leader car. It was interpreted that drivers try to see the space ahead of their leader car. By considering this assumption and knowing that the location of the driver is in the left side of the vehicle, therefore drivers needed a smaller lateral distance to provide the visibility in the tendency to the left in non-coaxial behavior. For more investigation of this interpretation and hypothesis, some drivers, who were familiar with the road, were interviewed. Most of them said that they keep lateral distance while driving in order to provide more visible space and also the possibility to avoid of an accident when the leader car suddenly breaks. Time headway and lateral distance showed that drivers, who tend to the right or overtake on the right, use sharper steering angle and keep less safety margin of lateral distance with the leader car. The results showed that the percentages of drivers who tend to the left are equal to drivers who tend to the right. The reason has been interpreted such that because when three cars are in continuous positions and the middle car supposedly tends to the right, naturally, its follower vehicle will tend to the left. Of course, it begs the question of whether the third car really uses this lateral distance. In other words, it can be said that the third driver may just follow the lane. According to the fact that non-lane-based behavior is common among Iranian drivers, at least it could be said that the third driver gets advantages from such a lateral distance and drives accordingly.

Figure 7 shows a quadratic polynomial function can be applied to the relationship between speed and the frequency of the non-coaxial behavior. It can be seen, at higher speed the non-coaxial behavior was reduced, as the headway among vehicles increased and vehicles less affect each other. By reducing speed or increasing density, vehicles more affect each other. They try to keep visual space by the means of non-coaxial behavior. But this trend would continue up to where vehicles fill the free spaces. In other words, in higher density vehicles force each other to stick to the path of leader car. Thus the number of non-coaxial car-following would be reduced. As Figure 9 shows, the percentage of happening non-coaxial behavior in a traffic jam was negligible. It can be inferred that non-coaxial behavior would be a response to environment and Iranian drivers learned it to maintain safety.

In non-lane-based behavior, the following car always considers two measures of headway and lateral distance. Also during overtaking, drivers at different time periods maintain headway and lateral distance, correspondingly. Therefore, by considering that follower vehicle has lateral speed, overtaking can be considered as a part or continuation of the non-lane-behavior. It led that both non-lane-based following and overtaking behavior were investigated simultaneously.

Finding the threshold of starting following behavior is one of the important issues in modeling car following. In other words, if the distance between two vehicles is beyond this threshold, the follower would show random behavior which would not relate to the leader car. It could be said that in this case, free driving occurs. According to a previous study by the authors [23] and also, according to the headway and lateral distance diagrams in this paper, it can be found that most drivers began to adopt a lateral distance in distance less than 2 sec. Hence, most probably, this value can be called as the threshold for the following behavior. In other words, by reaching the threshold of 2 sec, drivers start to change the lane. As mentioned previously, Iranian drivers accept following headway less than 2sec and this threshold can be named as the threshold for starting following, in which many of drivers try to change their lane rather than following leader vehicle. For more detailed, it requires a lot of recorded data from inside of the car.

Lateral distance on the left side and were compared with the right side. For comparison, three measures were considered: lateral speed, steering angle and the final lateral distance when two cars are parallel. The final lateral distance explains the distance between two cars that are next to each other and they are moving in parallel. In other words, their longitudinal distance is zero. All these three measures indicate that drivers who overtake on the right are less cautious and are more aggressive. For overtaking on the left, criteria of steering angle and, the final lateral distance and the lateral speed difference between the follower and leader were 33%, and 28% and 15% lesser than overtaking on the right.

The lesser caution while overtaking on the right rather than on the left side can be explained by two reasons: Firstly, drivers who overtake on the right would be more aggressive and less concerned with safety issues. Secondly, drivers always tend to overtake on the left and overtaking on the right is an emergency and it is acceptable when the driver is forced. Therefore, they have to accept lesser safe conditions for overtaking.

How several cars in traffic flow can move along and parallel to each other would be explained by estimating final lateral distance. The intersection of the fitted curve on the headway and lateral distance diagrams with the horizontal axis (headway equals zero), which represents the lateral distance of the center to center of the vehicles, shows the safety area that other drivers consider crossing another car. It is approximately 660 centimeters ($2 \times 330 = 660$). By considering the standard lane width in Iran(365 cm based on HCM), the considered safe space must be 720 centimeters (This number is the sum of the lane width in which the car is moving (365cm) and 2×182.5 cm distances, between two beside cars). It would show how a road can accommodate vehicles more than its lanes in its width.

8. Conclusions

By analyzing the non-lane-based behavior of Iranian drivers in the freeway, the following results were obtained:

- Non-lane-based behavior would be due to the effect of existence of other cars in the traffic flow. By increasing the vehicles in traffic flow, this behavior is more obvious so that the density of the flow extends as far as decreases the non-lane-based behavior and the driver would be forced to move behind the leader vehicle.
- Tendency to right and left side would naturally be equal. But the cars that tend to the right would maintain larger lateral distance.
- Field observations and interviews demonstrated that there would be two reasons for non-coaxial driving behavior: providing more visible distance and increasing the possibility of escaping in sudden braking and avoiding rear-end collision.
- For overtaking on the left, criteria of steering angle and, the final lateral distance and the lateral speed difference between the follower and leader were 33%, and 28% and 15% lesser than overtaking on the right.
- The time headway threshold for initiation of car-following behavior in Iranian drivers would be approximately 2 seconds.
- The roads in Iran can accommodate vehicles in their width more than number of lanes. The lane width should be revised based on the speed.

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10. Conflicts of Interest

The authors declare no conflict of interest.

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