

Retraction

Retracted: Estimating Lane Change Duration for Overtaking in Nonlane-Based Driving Behavior by Local Linear Model Trees (LOLIMOT)

Mathematical Problems in Engineering

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This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

- (1) Discrepancies in scope
- (2) Discrepancies in the description of the research reported
- (3) Discrepancies between the availability of data and the research described
- (4) Inappropriate citations
- (5) Incoherent, meaningless and/or irrelevant content included in the article
- (6) Peer-review manipulation

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

References

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Research Article

Estimating Lane Change Duration for Overtaking in Nonlane-Based Driving Behavior by Local Linear Model Trees (LOLIMOT)

Ehsan Ramezani-Khansari D,¹ Masoud Tabibi D,² and Fereidoon Moghadas Nejad D³

¹Transportation Engineering, Amirkabir University of Technology (Tehran Polytechnic), Tehran, Iran

²Transportation Engineering, Road Traffic Injury Research Center, Tabriz University of Medical Sciences, Tabriz, Iran ³Transportation Engineering, Civil Engineering Department, Engineering Faculty,

Amirkabir University of Technology (Tehran Polytechnic), Tehran, Iran

Correspondence should be addressed to Ehsan Ramezani-Khansari; e.r.khansari@aut.ac.ir

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Lane change (LC) is one of the main maneuvers in traffic flow. Many studies have estimated LC duration directly by using lanebased data. The current research presents an estimate of LC duration for overtaking maneuver in nonlane-based traffic flow. In this paper, the LC duration is estimated implicitly by modeling lateral speed and applying the length of required lateral movement to complete the LC maneuver. In lateral speed modeling, the local linear model tree is applied which consists of three variables: the initial lateral distance, longitudinal speed, and time to collision (TTC), which itself is a function of the relative speed of follower and the distance between the two vehicles. The initial lateral distance is the relative transverse distance from which the following vehicle initializes the LC. The range of lateral speed was estimated between 0.5 and 5 km/h, which resulted in the LC duration between 2.5 and 24 sec. The results indicate that the lateral and longitudinal speed would be inversely related, while the lateral speed and the initial transverse distance as well as TTC would be directly related. The findings also indicate that TTC can be assumed as the most important factor affecting lateral speed. TTC at 8 sec can be considered as the threshold for its effect on the LC duration since at longer TTCs, and the lateral speed has remained almost constant. When TTC is longer than 8 sec, it would not affect the LC duration.

1. Introduction

LC maneuvre is referred to as a driving maneuvre in which a vehicle moves from current lane to another where both of them are in same direction. Lane-changing, car-following, and gap acceptance models are the core of all micro-simulation softwares [1]. Driving behaviors can vary based on the country, region, and so on. Investigating LC behavior helps the traffic engineers to better estimate, predict, and plan for traffic flow. Due to the importance of the LC maneuver in traffic flow, many researchers have studied its modeling and decision-making process [2–5].

Finnegan and Green reported that lane-changing takes between 4.9–7.6 sec depending on the traffic condition and direction of lane-changing [6]. Hetrick used an instrumented vehicle to investigate LC behavior. The range of LC duration was measured about 3.4–13.6 sec by navigating 16 drivers to a predefined route. His research also concluded that the LC duration for young drivers was significantly shorter than elderly drivers. The average LC time was reported about 6 sec [7]. Hanowski in Virginia transportation institute used an instrumented vehicle to assess of the impact of fatigue on occurring accidents. Results driven from 42 drivers in the research indicated that LC duration was about 1.1–16.5 sec. LC initiation rule in his research considered the moment when the wheel of the subject vehicle crossed the lane marking [8].

In another research performed by Salvucci and Liu, 11 participants were examined by using a driving simulator. The simulated driving environment included a two-way, two-lane highway without any off-ramp or on-ramp in a medium-fidelity driving simulator. Recorded data included steer signals, throttle position, eye movement, and speed. Data were driven from 401 participants using the simulator resulted in a mean LC duration of about 5.14 sec. They also concluded that drivers slow down slightly before initiating the LC and increase the speed after initiating the LC [9].

Toledo et al. investigated LC durations by NGSIM dataset. These data were gathered from I-80 Emeryville in California by a camera that was mounted in a high-rise building. They extracted vehicle trajectory data from the observed segment. Variables including traffic characteristics and position of subject vehicle (related to the surrounding vehicle) were determined for each lane-changing. They found that LC behavior of heavy vehicles was different from passenger cars. Therefore, they made completely two separate models for each type of vehicles with specific parameters. They showed that traffic density was the most important variable that affected LC duration. The higher the traffic density, the greater the LC duration. The range of LC duration was measured between 1–13.3 sec, with a mean value of 4.6 sec and a standard deviation of 2.3 sec [10].

Moridpoor et al. conducted research to investigate the increase/decrease in speed in passenger cars compared with heavy vehicles at the time of lane-changing. They selected two segments of highways in California. They applied 42 LCs for each type of vehicle. The LC duration of passenger cars was reported between 1.1–8.9 sec with a mean of 4.8 sec and a standard deviation of 3.7 sec. However, the LC value for heavy vehicles was reported 1.6–16.2 sec with an average value of 8 sec and a standard deviation of 3.7 sec. Their results showed that the required time for heavy vehicles for LC maneuver was 70% greater than passenger cars [11].

Cao et al. modeled LC duration in an urban arterial road. They used a camera that mounted on a high-rise building for recording video of a road segment with a length of 140 m. The rule for starting the LC was the time instant by which the subject vehicle moves out of the current lane and enters to the target lane. They proved that time of lane-changing for heavy vehicles would be much longer than passenger cars. They reported the LC duration for passenger cars about 1–6.8 sec with a mean value of 2.54 sec and a standard deviation of 1.29 sec. For heavy vehicles, this was between 2–9.8 sec with the mean value of 4 sec and the standard deviation of 1.25 sec [12].

The definitions of initiation and completion of the LC maneuver have been different among various studies. In some cases, the lane-changing started when the first wheel passed lines (the lane markings) whereas in other cases it has been measured when the driver decides to change the lane [12, 13]. In Toledo's study lane-changing starts when the subject vehicle begins to move laterally relative to the current lane. The completion of maneuver is when the vehicle reaches the center of the target lane [10].

Li et al. studied LC duration by using data of 11000 vehicles, which had been extracted from naturalistic vehicle trajectory HighD dataset. By applying comparative univariate and regression analysis, they found that generalized Gamma distribution has high degree of coincidence with the nonparametric method in estimating the survival function [14]. Ataelmanan et al. employed the instrumented vehicle to examine LC duration in a highway in Kuala Lumpur. A total of 174 LC maneuvre incidences were observed in this study. LC data ranged from 0.90 to 10.52 seconds with mean and standard deviation values of 3.02 and 1.32 seconds, respectively. They found Lognormal distribution appropriate for recorded data [15].

Here, two aspects of LC duration have examined which were not considered in aforementioned investigations. First, many of them have assumed lane-based traffic flow, while in many developing countries, such as Iran, nonlane-based behavior is very common. In nonlane-based behavior, drivers do not pay attention to road markings, and it is more difficult to distinguish lane-changing maneuver. Second, LC duration of personal cars (PCs) was estimated by lateral speed indirectly and using microscopic characteristics. In other words, the studies have measured LC duration by considering macroscopic characteristics of the traffic flow.

The next section describes data collection. The third section describes the methodology for modeling LC duration. The fourth and fifth sections have been devoted to the local linear model trees (LOLIMOT) model and lateral speed modeling, respectively. The sixth section is about the results of this study. Finally, conclusions of the research have been addressed.

2. Data Collection

Data were collected from a length of about 100 m of Tehran-Karaj rural freeway, along Iranian road network. A 20meter-high camera was used to record the video (Figure 1). Films were analyzed by the semiautomated image processing method at intervals of 0.1 sec. In this method, an operator selects each vehicle, and the image processing program only tracks selected vehicles by using kernelized correlation filter. Although the method is very time-consuming and requires high processing sources, it was much more accurate than fully automated methods. Trajectory data of 2580 vehicles were extracted in 300 minutes. The maximum and the minimum speeds driven from data analysis were 127 and 61 km/h, respectively.

The longitudinal distance (or headway) and lateral distances have been measured, as depicted in Figure 2. Because of the selected road had limits and obligations for heavy freight vehicles, it has been only focused on the PC-PC situations. Therefore, other situations in which a heavy vehicle was involved have not been taken into account in this study.

3. Methodology

In this research, the lateral speed has been modeled to implicitly estimate the LC duration for overtaking. This method would be more convenient for traffic flow with



FIGURE 1: Snapshot of recorded films.



FIGURE 2: Lateral and longitudinal distance.

nonlane-based behavior. In nonlane-based behavior, the current and target lanes of LC maneuver cannot be defined accurately because the drivers pay attention to the leading vehicle instead of following lanes and obeying road markings.

To ensure that LC behavior was being carried out for overtaking, the average speed of the follower must be at least 10 km/h faster than the leader. The selected segment was far from any ramp or loop. By doing so, it can be concluded that almost all LCs were discretionary, and due to the speed advantages, because in the case of mandatory LCs, drivers may behave differently and take more risks [16, 17]. In this research, lane-changing starts when the subject vehicle begins to move laterally relative to the preceding vehicle.

Ramezani-Khansari et al.'s research demonstrated that Iranian drivers terminate overtaking maneuver at the lateral distance of 3.3 m related to the leading vehicle [18]. This means that due to the nonlane-based driving behavior, the driver could overtake without entering adjacent lane, instead she/he only requires adequately lateral distance, e.g., 3.3 m. Equation (1) reflects how the LC duration can be calculated having the lateral speed:

lane change duration (sec) =
$$\frac{3.3 \text{ m}}{\text{lateral speed (m/sec)}}$$
. (1)

Longitudinal speed, initial lateral distance (lateral distance at the beginning of the LC), and time to collision (TTC) have been used for modeling the lateral distance. These variables have been explained as follows: *Initial Lateral Distance*. The lateral speed of the follower may differ if she/he starts LC at different lateral distances. In other words, when the follower has some lateral distance, she/he has already done a part of the overtaking and lane-changing. Therefore, the initial lateral distance can be important to be recognized well and has been considered in the model.

Longitudinal Speed. Vehicle dynamics and driver behavior can vary at different longitudinal speeds. The reason why it has been considered is the sensitivity of drivers to changes in lateral position with respect to longitudinal speed.

TTC. It may be considered an important factor in two ways. On the one hand, TTC includes the relative speed of the following vehicle and headway (or distance) (equation (2)). Both of these factors may be considered in the driver's choice of lateral speed:

time to collision (TTC) =
$$\frac{\text{headway} - \text{vehicle length}}{\text{follower speed} - \text{leader speed}}$$
. (2)

On the other hand, two factors have been expressed in one factor by using TTC, which simplifies the final model of lateral speed. On the other hand, lateral speed can be affected by the lead-lag spacing in the target lane. The effect of leadlag spacing can be considered by TTC implicitly. It has been postulated that the driver has to accept higher risk (shorter TTC) for the LC if there is not enough lead-lag spacing. Due to lack of enough lead-lag spacing, the driver may approach the preceding vehicle, so she/he must change the lane at faster lateral speed. It can be concluded that there would be an inverse relation between the lead-lag spacing and TTC because it is not logical to tolerate shorter TTC when there is enough lead-lag spacing for LC. It is worth noting that TTC is in terms of time, which makes it independent of the speed and easier to build the model.

Figure 3 shows the relationship between the dependent and independent variables for estimating the lateral speed.

Given that the lateral speed model can be nonlinear and multiregime, linear and conventional mathematical models may not be appropriate. Therefore, the local linear model tree (LOLIMOT) has been used, which is a subset of neurofuzzy models whose flexibility in solving complex engineering problems has been evaluated [19–22].

LOLIMOT is an algorithm based on a problem-solving strategy in which a complex problem is solved by dividing the main problem into some smaller and simpler problems. Then, they are solved relatively independently by linear models (other regression models). Locally linear neurofuzzy structure with *M* neurons and *P* input is shown in Figure 4.

The most important issue in the success of such method is the initial problem segmentation algorithm. The LOLIMOT algorithm divides the input space using vertical axes. Each neuron contains a local linear model (LLM) and a validation function that specify the validity range of the LLM. For a model with P inputs, the output of each LLM is as follows:



FIGURE 3: Lateral speed modeling.



FIGURE 4: Locally linear neurofuzzy structure.

$$\hat{y}_{i} = \omega_{i0} + \omega_{i_{1}}u_{1} + \omega_{i_{2}}u_{2} + \dots + \omega_{i_{p}}u_{p}, \qquad (3)$$

where ω and u are the LLM parameters for neuron i and network inputs, respectively. The parameters of the LLMs are estimated independently by the least-squares error method, which makes the network less sensitive to noise because the noise affects locally. The validation functions (Φ_i) are usually selected as normalized Gaussian functions as follows:

$$\Phi_i(\underline{u}) = \frac{\mu_i(\underline{u})}{\sum_{j=1}^M \mu_j(\underline{u})}.$$
(4)

 μ_i in equation (5) refers to Gaussian functions whose centers and standard deviations are c_{ij} and σ_{ij} , respectively. Equation (6) shows the final output of the network.

$$\mu_{i}(\underline{u}) = \exp\left[-\frac{1}{2}\left[\frac{(u_{1} - c_{i1})^{2}}{\sigma_{i1}^{2}} + \dots + \frac{(u_{p} - c_{ip})^{2}}{\sigma_{ip}^{2}}\right]\right],$$
 (5)

$$\widehat{y} = \sum_{i=1}^{M} \left(\omega_{i0} + \omega_{i1} u_1 + \omega_{i2} u_2 + \dots + \omega_{ip} u_p \right) \Phi_i \left(\underline{u} \right).$$
(6)

The output of the network is the weighted sum of the LLMs, and therefore the network interpolates between the different LLMs with the validation functions. At the beginning of LOLIMOT, the entire input space has one neuron, but in each iteration, the input space is divided and another neuron is added. In each iteration, the worst LLM with more local error is selected and divided into two parts based on each input. The direction that creates the least modeling error is selected [23]. This procedure is repeated until achieving the desired answer. The LOLIMOT model is an iterative method and requires a stopping criterion. Here, the improvement in the coefficient of determination (R-squared) has been used as stopping criteria. The number of LLMs increases until it reaches the threshold of 1% progress of R-squared. In other words, the number of LLMs has been optimized based on the progress of R-squared.

4. Results and Discussion

In the LOLIMOT model, the lateral speed has been the dependent variable, where the independent variables have been assumed to be the longitudinal speed, TTC, and initial lateral distance. LOLIMOT tool box in MATLAB was used [23]. The trajectory data had some noises which have been seen in many data extracted from films [24]. To overcome this variation, the data are smoothed in each 0.5 and 1 sec, by applying a moving average method. The data set was splitted into training, validation, and testing by the percentage of 70, 15, and 15, respectively.

Figure 5 shows that using 70 LLM can result in an acceptable solution (R-square = 0.69) by using training and validation data. In Figure 5, blue and red lines (respectively, marked with triangular and squares) are R-squared and its progress, respectively.

Figure 6 also depicts the histogram error of estimating the lateral speed using LOLIMOT by using test data. The RMSE (root mean square error) index of the model has been addressed equal to 0.59.

Since the model includes four variables (three independent variables and one dependent variable), it is not possible to display these four variables in one figure simultaneously. Hence, one independent variable has been considered constant to picture the output of the model. Two variables have been placed on the horizontal and vertical axes. The fourth variable has been plotted inside the chart (referring to the legend). By doing so, four variables could be shown simultaneously.

Figures 7 and 8 show the relationship between the lateral speed and TTC when the initial lateral distance of the following vehicle has been categorized to 0–0.5 and 1.8–2.2 m, respectively.

It can be seen that the lateral speed has decreased by increasing the TTC. As the initial lateral distance has increased, the lateral speed slope has decreased. Figure 9, for instance, shows the relationship between lateral speed and initial lateral distance when TTC equals to 5 sec.

According to the results obtained from the LOLIMOT model, it can be seen that there has been inverse relationship between TTC and the lateral speed. It also can be concluded that by increasing TTC, the lateral speed has decreased, too. The figures also reflect that as the TTC increased and also the initial lateral distance increased, the slope of the lateral speed graph has decreased. It also indicates that an inverse relationship would exist between lateral and longitudinal speed,



FIGURE 5: Coefficient of determination of the estimated LOLIMOT model.





FIGURE 7: Relationship between the lateral speed and TTC in different speeds (assuming lateral distance varies between 0 and 0.5 m).



FIGURE 8: Relationship between the lateral speed and TTC in different speeds (assuming lateral distance varies between 1.8 and 2.2 m).



FIGURE 9: Relationship between the lateral speed and initial lateral distance in different speeds (assuming TTC equals to 5 sec).

in which the initial lateral distance could affect it. Findings also imply that at higher longitudinal speeds, drivers' sensitivity to lateral speeds would increase. In other words, when the longitudinal speed is high, the driver would apply less lateral speed to ensure safety and comfort. By increasing the longitudinal speed, the driver's inclination to higher lateral speed would decrease. When the vehicle had a large initial lateral distance (1.8 to 2.2 m), it has been seen that the slope of the lateral speed and TTC relationship chart was very low. It can be concluded that when the driver does not have to travel a longer distance to complete the LC and overtaking maneuver, she/he would be less affected by the TTC. In other words, increasing the initial lateral distance has reduced the effect of the TTC on the lateral speed.

It was observed that when the TTC has become more than 8 sec (the initial lateral distance between 0 and 0.5 m), the slope of the lateral speed diagrams has decreased and has become almost a straight line. This may indicate that the effect of TTC would diminish when it has passed 8 sec. It would correspond to free driving conditions in car-following behavior in which by increasing time headway to a specific value, the follower does not react to the leader.

According to the relationship between lateral speed and initial lateral distance (Figure 9), it can be seen that by increasing initial lateral distance, the lateral speed would increased. It can be seen that when the initial lateral distance has been larger and the required lateral distance for completing the LC maneuver has been shorter simultaneously, drivers have applied higher lateral speed because they have spent less time in LC maneuver. It can be said that the tendency of the drivers to higher lateral speed has increased with decreasing lateral distance. Accordingly, when the initial lateral distance has been smaller and the drivers have required longer lateral movement, simultaneously, the tendency to higher lateral movement has decreased.

In the proposed model, the lateral speed has been considered constant and equal to the average recorded lateral speed. It is expected that the lateral speed is lower at the beginning and end of the LC maneuver because it is a function of the angle of the wheels. In the LC, the angle of the wheels gradually increases and reaches a constant value and decreases again [25].

The LC duration has been estimated by using lateral speed and lateral distance, so it was expected that using the mean lateral speed would not have a significant effect on results. Due to the length of the recorded road segment, some LCs have been recorded incompletely. Using the average lateral speed could help to estimate them as well.

In this study, the aim of obtaining the lateral speed has been to estimate the LC duration; taking into account the estimated lateral speed has been between 5 and 0.5 km/h and the length of lateral movement for LC has been assumed equal to 3.3 m, the LC duration has been calculated between 2.5 and 24 sec.

The main limitation in this article was the length of recording data along highway, which was not so long to cover entire of all LC maneuvers. In other words, there were LCs that recorded incompletely. It should be mentioned as the average of the lateral speed was used, the effect of this limitation should be reduced significantly. Another limitation was the volume of traffic flow. The recorded data set only included uncongested condition (level of service A to C). So, congested condition should be examined.

5. Conclusions

LC is one of the main maneuvre in the traffic flow and is essential for all simulation programs. Studying LC duration in nonlane-based traffic flow is much difficult than lanebased because drivers do not consider road markings and lanes. So, it is not appropriate to estimate directly. By estimating LC duration indirectly, the estimate will be dependent on the microscopic characteristics of traffic flow rather than macroscopic characteristics, which make the estimation more specific for each vehicle and is more accurate. Here, LC duration has been achieved indirectly by using the lateral speed and the length of required lateral movement to complete LC maneuver. The LOLIMOT method has been used, by which the problem is divided into smaller local spaces and be solved through applying linear models to solve equations of these spaces.

It was found that there would be an inverse relationship between lateral and longitudinal speed, whereas a direct relationship was found between the lateral speed and both the initial transverse distance and TTC. TTC would be addressed as the most important factor affecting the lateral speed, but it affects the lateral speed up to a threshold. TTC was considered as it is a function of the relative speed of the follower and the distance between the two consecutive vehicles.

In this article, LC was modeled by using microscopic characteristics of subject and surrounding vehicles. However, it is interesting to consider driver factors such as age and gender. Furthermore, the vehicle and road type can affect results which can be studied.

Data Availability

The data used to support this study are available upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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