Traffic & Transportation

A Comprehensive Double Index Left-Turn Conflict Model at Contraflow Left-Turn Lane Intersections

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Original Scientific Paper
Submitted: 27 Feb 2024
Accepted: 12 Jun 2024

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Publisher:
Faculty of Transport and Traffic Sciences, University of Zagreb

ABSTRACT

The study comprehensively evaluates the safety of contraflow left-turn lane intersection, characterised by unique traffic operational features distinct from conventional intersections. The evaluation specifically focuses on the process of left-turning vehicles entering the receiving lane within the intersection. The vehicle arrival rate of left-turning vehicles is analysed to identify vertical conflict features in contraflow left-turn lane design. By subdividing lanes within the intersection, the study delves into the lateral displacement of left-turning vehicles to establish lateral conflict features. To quantify the overall conflict potential, a multiple unit conflicts index is derived by integrating both vertical and lateral conflict features. Furthermore, the double index left-turn conflict model is constructed by introducing the potential collisions severity index during the conflict process. The results indicate that conflict hotspots along the vehicle travel path are primarily concentrated in two regions: (1) at pedestrian crosswalks and within a 2-meter extension; (2) within a range of 6 to 18 meters from the pedestrian crosswalk. The proposed model demonstrates good evaluation effectiveness, providing valuable insights into enhancing the safety of contraflow left-turn lane intersections.

KEYWORDS

contraflow left-turn lane intersection; traffic conflict; double index; traffic safety.

1. INTRODUCTION

With the development of the global economy and the acceleration of urbanisation, road traffic has become increasingly important in people's lives. However, accompanying this trend is the frequent occurrence of traffic accidents, resulting in casualties and property losses. According to the 2023 Global Status Report on Road Safety, road traffic injuries remain a leading cause of death for individuals aged 5 to 29, and rank as the 12th leading cause of death when considering all age groups [1]. A reasonable evaluation of road traffic safety is fundamental to improving driving security, reducing traffic accidents and mitigating the severity of accidents and losses. Therefore, road traffic safety assessment holds significant practical and engineering significance.

Signalised intersections, integral to urban road networks, play a pivotal role for managing traffic conflicts and congestion. Among them, left-turn traffic flow has been a bottleneck for both safety and efficiency improvement at signalised intersections. In recent years, researchers have introduced diverse unconventional intersection designs aimed at optimising traffic flow efficiency at signalised intersections [2–3]. In domestic and international research, the term 'contraflow left-turn lane (CLL) intersection' is alternatively referred to as 'exit lanes for left-turn (EFL) intersection' [4–5]. These intersections have gained attention in China due to their cost-effectiveness and minimal reconstruction requirements. Unlike conventional intersections, CLL intersections exhibit distinctive operational characteristics that may contribute to unsafe driving behaviours among left-turning motor vehicles. The effectiveness of the designed CLL is reduced by the driver's inappropriate lane selection. In the process of completing the left turn, the safety of the vehicle is easily affected by micro-driving behaviour.

Existing studies mainly focus on safety evaluations of left-turn vehicles at conventional intersections. Considering that the concept of the CLL design is proposed specifically for the left-turn motor vehicles, as illustrated in *Figure 1*, the CLL intersection incorporates a designated placement of the median barrier opening at an appropriate distance from the stop line at the entrance [6]. Additionally, a pre-signal is positioned at the opening, allowing left-turning motor vehicles to use opposing exit lanes N_i (i=1,2,3,4) for executing left-turn manoeuvres. This coordination, considering both the main signal and pre-signal control conditions, enhances the overall capacity for left-turning motor vehicles. Within the theoretical signal control system of the CLL design, traffic flows 9, 10, 11 and 12 are subject to pre-signal control. Special attention needs to be given to the fact that there is an early close time for the pre-signal. For instance, traffic flows 11 and 12, controlled by pre-signals, are closed a few seconds earlier than traffic flows 7 and 8 controlled by the main signals. The purpose is to avoid any left-turn traffic remaining in the contraflow left-turn lane after the end of the stage two, which may lead to conflicts with opposing through movements. The value of the early close time of the pre-signal is related to the length of the contraflow left-turn lane and the average speed of vehicles. By adjusting the opening and closing times of the pre-signal, conflicts with opposing through movements can be effectively avoided. Therefore, this study does not consider conflicts between left-turning vehicles on the CLL and oncoming vehicles.

Throughout the left-turning manoeuvre of motorised vehicles at a CLL intersection, the merging of vehicles occurs as those using the contraflow left-turn lane integrate with vehicles from the conventional left-turn lane, leading to the convergence of both lanes into a single lane. In this scenario, significant deceleration or stopping manoeuvres are generally not undertaken by following vehicles. Due to safety concerns, following vehicles often exhibit slight steering adjustments or deceleration, which can be defined as collection conflict [7]. *Figure 2* shows the specific form of this conflict.

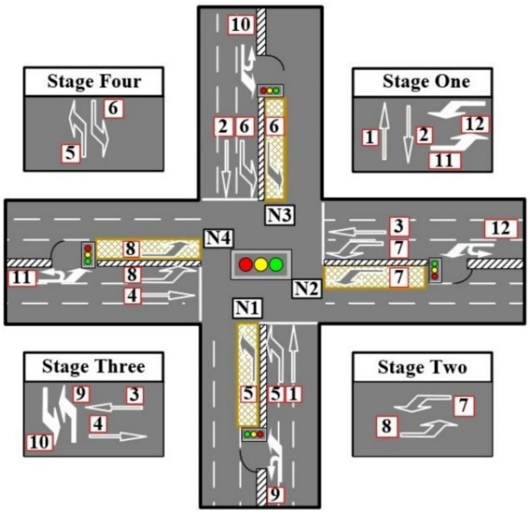


Figure 1 – Geometric design and signal control scheme for the CLL intersection

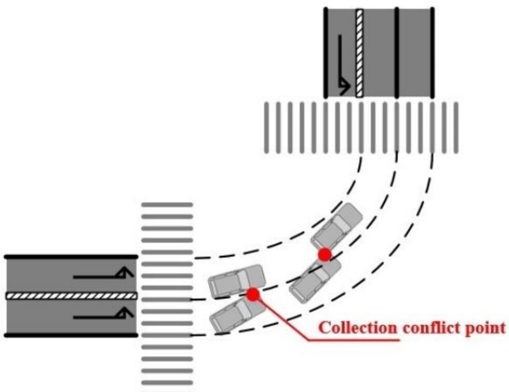


Figure 2 – Collection conflicts of left-turn vehicle within the intersection

The concept of traffic conflicts originated in the United States, and the Traffic conflict technique (TCT) was developed to address the limitations in traffic accident data collection [8–9]. Originally characterised by the presence of avoidance behaviours, the definition of traffic conflicts has evolved to focus on temporal or spatial proximity [10]. Regarding conflict measurement indicators, Paul et al. [11] proposed a new indicator reflecting the probability of rear-end collisions, which proves to be effective. Some scholars argue that field-collected traffic conflict data, considering multiple real-time factors, demonstrates stronger correlations with traffic accidents than single objective indicators [12–13]. For traffic conflict identification, researchers like Lu et al. [14] use deep unsupervised learning to learn the representations of time to collision (TTC) and driver control profiles, and clustering these representations into conflict and non-conflict groups. To enhance the identification rate of traffic conflicts, some scholars [15–16] analysed the relationship between physical attributes and vehicle conflicts, leading to the development of a conflict identification model.

In addition to assessing traffic conflicts, some scholars have conducted comprehensive safety analyses for unconventional intersections. Guo et al. [17] evaluated safety using an extreme conflict model and considered the instability and heterogeneity of conflict extremes. Cai et al. [18] examined multiple factors for traffic safety analysis, and other scholars [19–20] analysed the impact on road traffic safety by considering indicators, incorporating indicators such as collision severity, types, causes, speed and occupancy rates. At present, research on the safety of CLL intersections has only been conducted by a small number of scholars. Zhao et al. [21] conducted an analysis of four potential safety issues based on field evaluations. But they neglected to consider human factors in their analysis. Research has shown that an improvement in operational efficiency can be observed when drivers possess a high level of proficiency in CLL [22]. Zhao et al. [23] employed driving simulators to investigate drivers' responses when they meet CLL under four different signage conditions.

In conclusion, there is a lack of safety research on CLL intersections in unconventional intersection scenarios. However, with the increasing importance of traffic congestion, this design method is becoming an indispensable part and it cannot be ignored. Moreover, most vehicle safety studies treat conflict objects as point masses along the trajectory of conflicting vehicles, neglecting factors such as vehicle size and angle offset, which has limitations.

The purpose of this paper is to enhance the driving safety of left-turning vehicles on the CLL intersection. In order to enable a thorough analysis of the safety conditions within CLL intersections, this study constructed a double index conflict model. Firstly, continuous left-turn vehicle trajectories under the design of CLL at an intersection in Xinxiang, China were acquired utilising data acquisition equipment. Then, the analysis encompasses the characteristics of the arrival of left-turning motor vehicles, the operational trajectory of left-turning motor vehicles within the intersection, and the lateral offset characteristics of turning vehicles during lane operations. Break through the situation that the conflict object is regarded as a mass point in the conflict vehicle track in a large number of previous vehicle safety studies. Finally, by considering the width, weight, speed and other factors of different type left-turning vehicles, and by integrating the traffic characteristics of left-turning vehicles, a double-index collection conflict model is established for CLL intersections. The model is based on micro-units, with the internal area of the entire intersection divided into several cells of uniform size. This paper is organised as follows: Section 2 describes the methods for data acquisition and processing. Section 3 provides the criteria for constructing conflict assessment models. The process of establishing double index models is outlined in Section 4. Case study is conducted in the Section 5.

2. DATA COLLECTION AND PRE-PROCESSING

In order to accurately capture sufficient data regarding traffic flow status and specific traffic conflict at CLL intersections, an investigation was carried out in Xinxiang City. Considering factors including nearby buildings, road hierarchy and suitability for data acquisition equipment, we selected the intersection at Heping Avenue and Jinsui Avenue. The road hierarchy of this intersection is classified as a major arterial road. *Table 1* provides the specific geometric design parameters for the intersection. The data collection period was from 7 May to 11 May 2023, one of which is a non-working day. The data comprised of morning peak, evening peak and off-peak periods, with a total of 10 hours of valid data. This study used intersection data to develop a double-index left-turn conflict mode and to evaluate intersection safety.

Table 1 – Design parameters for CLL intersections

<table>
<tr><th>Intersection name</th><th>Size parameter</th><th>North approach</th><th>South approach</th><th>East approach</th><th>West</th><th>Intersection name</th></tr>
<tr><td rowspan="5">Heping Avenue and Jinsui Avenue</td><td>Conventional left-turn lanes</td><td colspan="4">1</td><td rowspan="5">City Park, City Sports Centre</td></tr>
<tr><td>Contraflow left-turn lanes</td><td>1</td><td>1</td><td>2</td><td>1</td></tr>
<tr><td>Contraflow left-turn opening (m)</td><td>34</td><td>25</td><td>30</td><td>32</td></tr>
<tr><td>Lane width (m)</td><td>2.5</td><td>2.7</td><td>2.5</td><td>2.5</td></tr>
<tr><td>Number of exit lanes</td><td>3</td><td>3</td><td>4</td><td>4</td></tr>
</table>

Contraflow left-turn opening: the length of the opening that allows vehicles to enter the mixed use area.

Data collection for this study was conducted using a combination of DJI Mavic 2 drones, cameras and rangefinders. Field data collection was conducted following specific requirements and methods outlined. Data collection requirements specify that the areas surrounding the CLL intersection should be open and flat with minimal tree shade, facilitating aerial drone photography. *Figure 3* shows the specific data collection methods.

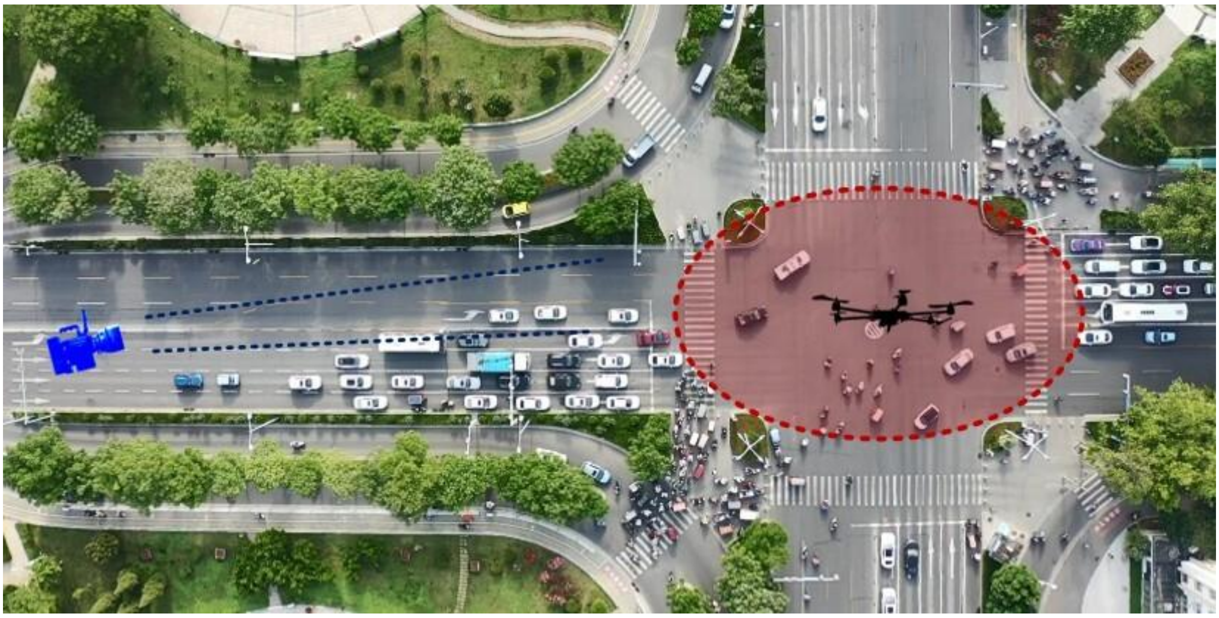


Figure 3 – Specific data collection methods

The vehicle's running trajectory, lateral displacement and collection conflicts data were obtained by using the Tracker software, primarily developed by researchers for tracking object centroids in videos, based on the collected video footage [24]. The validity of the extracted vehicle trajectory data was verified [25].

In the actual measurement data, the identification and exclusion of abnormal data follow these steps: (1) As a result of the influence in wind direction, the coordinate axis of the drone's got shot was changed, necessitating real-time data correction to achieve uniformity in the data axis. (2) Given that different quantities of mixed-use zones can result in varied driving behaviours, the data in this study is solely focused on the northern entrance of the surveyed intersection. This study primarily focuses on the investigation of traffic safety between a standard left-turn lane and a contraflow left-turn lane. The specific data acquisition type and processing are illustrated in *Figure 4*.

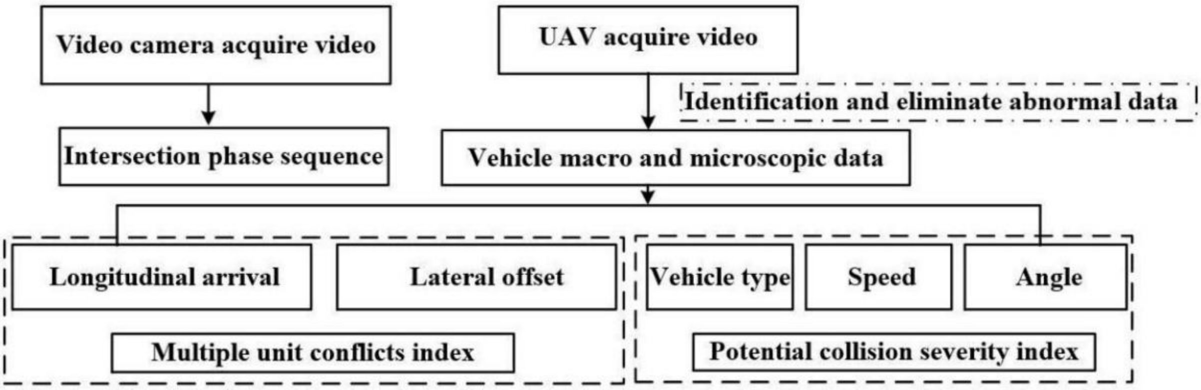


Figure 4 – Data acquisition and processing workflow

3. DOUBLE INDEX MODEL CONFLICT JUDGMENT

3.1 Vehicle trajectory characteristics

By observing, investigating, analysing and processing the sample data, we established a coordinate system for the intersections. The intersection centre served as the coordinate origin, the median separator at the north entrance was utilised for the y-axis and the x-axis was aligned with the east entrance direction. *Figure 5* depicts the measured trajectory curves of vehicles passing through the intersection. It is observed that left-turning vehicles choose the third and fourth lanes when entering the exit lane, which may lead to the occurrence of collection conflicts. Using the trajectory of the observed left-turning vehicle in the collected data as the centreline, this study traces a curved diversion path with the same width as the lane to analyse the lateral offset. By analysing the trajectory characteristics of left-turning vehicles within CLL intersections, the driving paths of these vehicles were determined. This section laid the foundation for lane boundary and lateral offset analysis.

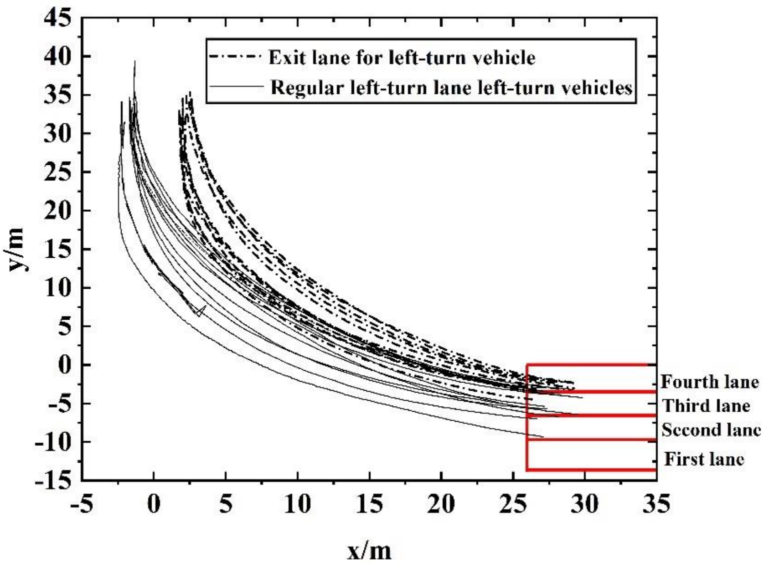


Figure 5 – Trajectories of left-turning vehicles

3.2 Microscopic unit establishment

To assess traffic safety conditions at CLL intersections, the internal area is subdivided into grid units. The intersection's centre point serves as the coordinate origin, and the medial divider of the north approach designates the positive x-axis direction. The grid unit dimensions, both in length and width, must be smaller than the vehicle width. These parameters characterise vehicle arrivals, with a unit considered occupied if any part of a vehicle is within it. In this coordinate system, the unit at the i^{th} row and j^{th} column is represented as (i,j).

3.3 Conflict judgment criterion

In the process of completing a left turn, vehicles coming from two different entrance lanes are prone to track crossing, resulting in collection conflict. In view of the collection conflict, this section establishes many micro-cells of the same size within the intersection. The criterion for identifying a conflict is the simultaneous presence of two vehicles in the same cell.

4. DOUBLE INDEX LEFT-TURN CONFLICT MODEL

4.1 Multiple unit conflicts index

In the process of constructing the first index, the traffic characteristics of left-turning vehicles at intersections are studied. This includes analysing statistics related to the vehicle arrival rate of left-turning vehicles, which constitute the longitudinal characteristics. By dividing the lanes within the intersection, an analysis will be conducted on the lateral deviation of left-turning vehicles, thereby forming the lateral characteristics. When a conflict appeared, the left-turn vehicle was not treated as a mass point, and the whole individual of the left-turn vehicle was fully considered. In this section, data fitting is performed using the statistical analysis software [26].

Accounting for conflicts between vehicles entering CLL and conventional left-turn lanes, a predictive model for the conflict probability of left-turn vehicles in any unit of the CLL intersection is established. K represents the vehicle trajectories, where generally two trajectories pass through a single unit [27]. The specific number of conflicts in unit (i,j) is determined by the following *Equations 1–2*. *Equation 1* represents a certain value indicating the conflict probability in unit (i,j). *Equation 2* represents the probability of a vehicle arriving at unit (i,j) along trajectory K. If there is no traffic flow arriving at a certain unit along a particular trajectory, the probability of a vehicle arriving at that unit is considered to be 0.

$$P_{ij}=P_{Gij}^{1}\times P_{Gij}^{2} \tag{1}$$

$$P_{Gij}^{k}=P_{Aij}^{k}\times P_{hij}^{k} \tag{2}$$

where P_{Aij}^{k} represents the longitudinal arrival distribution of vehicles along trajectory k in unit (i,j); P_{hij}^{k} represents the lateral offset distribution of vehicles along trajectory k in unit (i,j).

Longitudinal arrival characteristics

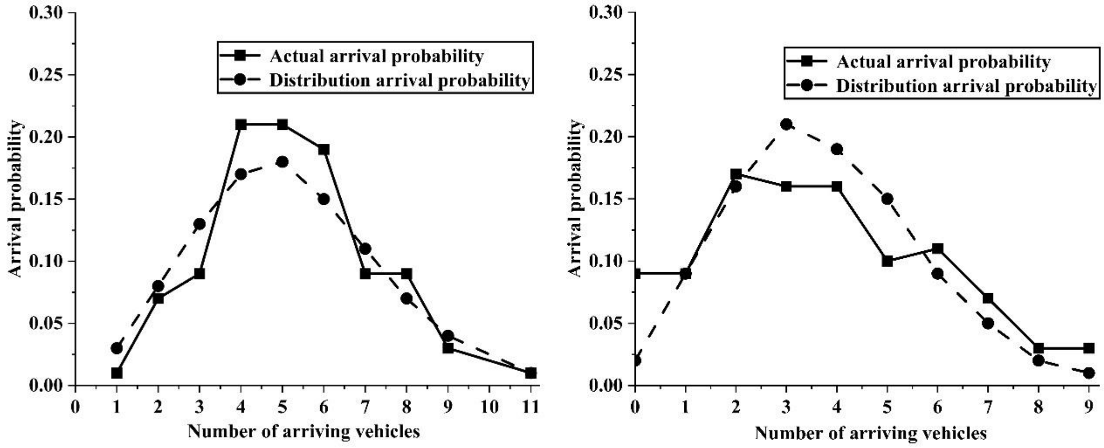
CLL intersections exhibit distinct traffic operation modes, leading to differences in the arrival distribution of left-turning vehicles compared to conventional intersections. To observe the arrival of vehicles at specific points within the signalised intersections, we conducted periodic observations of both the conventional left-turn lanes and the CLLs. The analysis of data from an intersection in Xinxiang City, namely Heping Avenue and Jinsui Avenue intersection, revealed that the arrival of vehicles in the conventional left-turn lane and CLL follows the Poisson distribution.

$$P_A(x)=\frac{\lambda^x e^{-\lambda}}{x!} \tag{3}$$

The above *Equation 3* represents the general distribution form of left-turning vehicles that have arrived. The specific parameter values and the goodness of fit of the distribution are as follows. Since the vehicle arrivals mentioned above follow discrete distributions, an Anderson-Darling test was conducted on the distribution represented by the equation. The test data is shown in *Table 2*. The null hypothesis (H_0) states that the sample distribution follows the above function. If the statistics A^2 are less than the critical value within the 99% confidence interval, with a significance level of 0.01, leading to the acceptance of the original hypothesis. The vehicles reaching the fitted curve can be seen in *Figures 6a and 6b*. The range of error for conventional lane vehicles is between 0% and 4%. The range of error for CLL vehicles is between 0% and 7%.

Table 2 – Goodness of fit test results and related parameter variables for vehicle arrival counts

Data category	λ	A^2	Critical value	Test result
Conventional lane	5.13	3.501	3.907	A^2 < critical value
Contraflow lane	3.76	3.743		



(a) *(b)*

Figure 6 – Vehicles reaching the fitted curve: a) Conventional left turn lane vehicle reaches the fitted curve; b) CLL vehicle reaches the fitted curve

Lateral offset characteristics

In existing studies on vehicle safety using traffic conflict indicators, the vehicle's trajectory is typically treated as a consistent straight line. However, in actual situations, vehicles exhibit lateral distance between their final and initial states, known as lateral offset. The conflict value discussed in this study is not limited to a single point but represents the value within an area, termed as regional conflict value.

Investigating the running trajectories of left-turning vehicles at the intersection Heping Avenue and Jinsui Avenue intersection in Xinxiang, the lateral offset is analysed. The entire lane is divided into six intervals, as shown in *Figure 7*, with the 0 located at the lane centreline. The lane is divided into six intervals, and the left-turn lane width is 3 meters. The right side of the left-turn direction is considered as the positive offset direction. Statistical analysis is conducted on the observed sample data, and the same approach is adopted to examine the lateral offset of left-turning vehicles with the vehicle centreline setting as the boundary used the centre of the license plate.

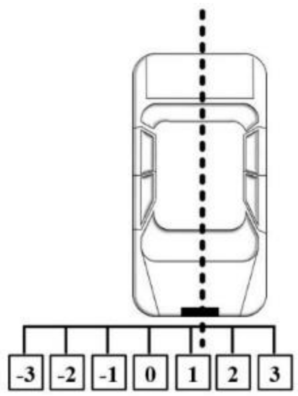


Figure 7 – Vehicle offset diagram

Using the described method, we investigated and analysed data at intersections to extract lateral offset positions of left-turning vehicles. Video data processing revealed that the lateral offset during the turning process conforms to the normal distribution:

$$f=\frac{e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}}{\sigma\sqrt{2\pi}} \quad (4)$$

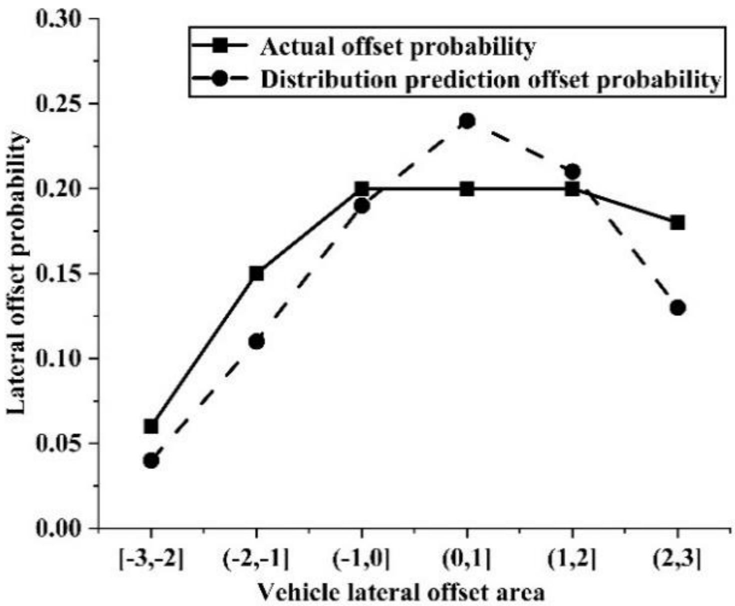
where σ is the distribution of standard deviation, with a value of 1.64; μ is the mean distribution, with a value of 0.63.

The above *Equation 4* represents the general distribution form of lateral displacement for left-turning vehicles. The goodness of fit of the distribution is detailed as follows. The measured data was subjected to an Anderson-Darling test to examine the hypothesis H_0, which states that the sample distribution follows the distribution. The conventional lane vehicle statistics A^2 is 0.875 and the critical value is 3.907. The CLL vehicle statistics A^2 is 0.534 and the critical value is 3.907. At a 99% confidence interval and a significance level of 0.01, the results indicated significance ($A^2 <$ critical value). Therefore, the null hypothesis was accepted.

The probability of lateral offset signifies the likelihood of a vehicle occupying a specific point within a lane. This is represented by the difference between the vehicle centreline and the lane centreline. The probability calculation formula for left-turn lateral offset is as follows.

$$P_h(x)=\int_a^b f\,dx \quad (5)$$

where, a and b represent the interval occupied by the lateral offset of the vehicle. The comparison between the predicted probability values of the distribution and the actual probability values can be observed in *Figure 8*. The margin of error ranges from 1% to 5%.



Figures 8 – Vehicles lateral offset the fitted curve

4.2 Potential collision severity index

The key to the evolution from traffic conflicts to traffic accidents lies in whether drivers can successfully take evasive measures after conflicts occur [28]. By analysing the severity of the potential collision, we can find out the seriousness of the accident collision caused by improper risk aversion in the traffic conflict [29]. The interaction between vehicles during accident collisions can be derived from the conservation of kinetic energy.

During data investigation and analysis, it was observed that different vehicle types have different masses, as detailed in *Table 3*. After a vehicle collision, kinetic energy transforms into destructive energy within the traffic conflict. Therefore, the potential collision severity between motor vehicles can be represented by the conservation of kinetic energy, as depicted in *Equation 6*.

$$E=\frac{1}{2}\frac{M_1M_2}{M_1+M_2}[(V_1 \sin\alpha)^2+(V_1 \cos\alpha - V_2)^2] \tag{6}$$

where E represents the destructive energy inherent in the traffic conflict, in J; M_1 and M_2 represent the weights of the following and leading vehicles, respectively, in kilograms (kg); V_1 and V_2 are the instantaneous speeds of the following and leading vehicles at the moment of the collision (km/h), with the collision angle represented by α [16].

Table 3 – Different vehicle types

Type	Vehicle	Mass
Small vehicle	Micro-electric vehicle	1000 *kg*
	Small car (Width less than 1.6 meters)	1200 *kg*
Large vehicle	Bus	20000 *kg*
	Tour bus	30000 *kg*
	Van	10000 *kg*

4.3 Double index left-turn conflict model

In this study, the multiple unit conflicts index will be combined with the potential collision severity index to construct a double index left-turn conflict model. This approach enables the assessment of the risk of collection conflicts occurring among left-turn vehicles within the CLL intersection. Due to the index unit differences, we refer to previous literature [30] and use parameters of 0.4 and 0.6 to construct the model. After normalisation, the energy released by traffic conflict collision is expressed as C, and 112500 J is used as the energy classification threshold [31]. The conflict risk index of left-turning vehicles is expressed as φ. ${P_{Gij}}^K$ represents the probability of a vehicle arriving at unit (i,j) along trajectory K. The calculation formula is as follows:

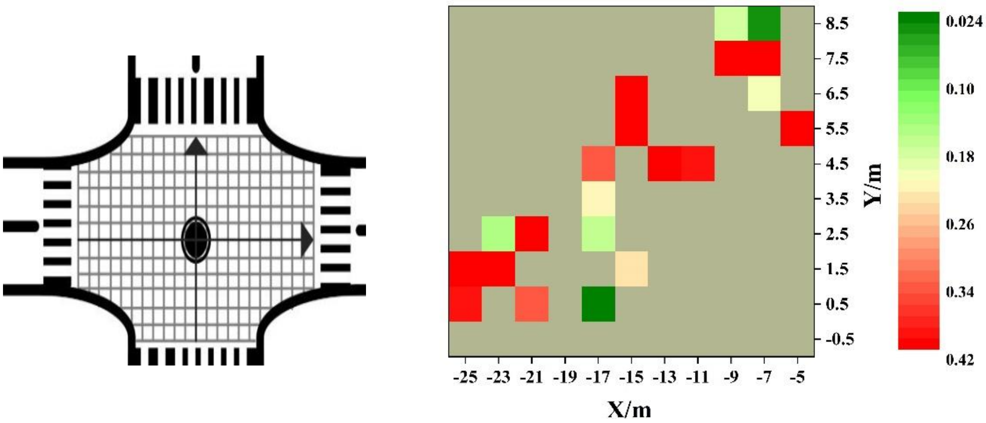
$$C=\begin{cases}\frac{E}{11250}, 0\leq E\leq 11250J\\ 1, E>11250J\end{cases} \tag{7}$$

$$\varphi=0.4*C+0.6*{P_{Gij}}^K \tag{8}$$

5. CASE STUDY

5.1 Model validation

In this study, analysis was conducted using a unit length of 2 meters. The coordinate system establishment and the threshold analysis of the results are illustrated in *Figures 9a* and *9b*. The south and east directions of the intersection are taken as the positive directions of the X axis and Y axis, respectively, and the X axis is aligned with the central separation zone of the north entrance. The model thresholds are defined as follows: 0 to 0.18 is considered as a slight conflict, 0.18 to 0.34 as a general conflict and exceeding 0.34 as a severe conflict.



a) *b)*

Figure 9 – The process and results of double index left-turn model construction: a) The coordinate system of the intersection units; b) The conflicting results of the double index model

In order to minimise the error, considering that the time measurement index is widely used to describe the traffic conflict safety problems in the existing research, this study uses the PET (Post Encroachment Time) index to study the vehicle trajectory of the CLL intersection. The results are compared with the model results of this study.

The PET index, as a type of time measurement indicator, is particularly well-suited for addressing conflicts involving trajectory intersections. The PET value refers to the time gap between the departure of the leading vehicle's rear end and the arrival of the following vehicle's front end at the conflict point. By referencing previous research [7], the PET thresholds are selected as follows:

$$PET = \begin{cases} \text{Severe conflict, } PET \leq 1.5 \\ \text{General conflict, } 1.5 < PET \leq 2 \\ \text{slight conflict, } 2 < PET \end{cases} \tag{9}$$

After the thresholds are chosen, several units are randomly selected to compare the severity of conflicts with the results of the model proposed in this study, as shown in *Table 4*. Through comparison, it can be observed that the conflict categories occurring in the same locations are largely similar. The model results are essentially consistent with the actual observations.

Table 4 – Comparison of verification results

Coordinate	Probability of this model	Degree of conflict	PET	Degree of conflict
(-17.78, 3.182)	0.224	*General*	1.71	*General*
(-6.913, 6.882)	0.419	*Severe*	1.44	*Severe*
(-22, 0)	0.413	*Severe*	1.208	*Severe*
(-8.992, 7.004)	0.417	*Severe*	1.242	*Severe*

5.2 Model applicability analysis

In order to verify whether the double index model proposed in this study can be applied to other CLL intersections, an analysis of the model's applicability was conducted in this section. During the applicability analysis, the potential impact of different approach widths on various driving behaviours was taken into account. In this section, intersections with different lane widths are selected to verify the applicability of the double index model. Data collection, processing and analysis were conducted for the intersection of Xinfei Avenue and Pingyuan Road in Xinxiang City. This intersection also has the design characteristics of CLL. The applicability analysis process is consistent with the processing and analysis of constructing the double index model in this study. The specific geometric design parameters of this intersection are detailed in *Table 5*.

Table 5 – Specific geometric design parameters

Intersection name	Size parameter	North approach	South approach	East approach	West	Intersection name
Xinfei Avenue and Pingyuan Road	Conventional left-turn lanes	1				School, Library, Square
	Contraflow left-turn lanes	1				
	Contraflow left-turn opening (m)	47	31	30	30	
	Lane width (m)	2.8	2.5	3.4	2.8	
	Number of exit lanes	3	3	4	3	

The goodness of fit test results and related parameter variables of the longitudinal arrival distribution and lateral offset of left-turn motor vehicles at this intersection are shown in *Table 6*. At a 99% confidence interval and a significance level of 0.01, the critical value is 3.907. Therefore, the null hypothesis was accepted.

Table 6 – Goodness of fit test results and related parameter variables

Data category	λ	σ	μ	A^2	Test result	Error range
Conventional longitudinal arrival	6.2			1.964	A^2 < critical value	0%~6%
Contraflow longitudinal arrival	3.39			3.572		0%~9%
Lateral offset		1.67	0.29	0.944		2%~10%

Through the establishment of the double index model for this intersection, conflict location studies were conducted in this section. For details on the conflict locations and their corresponding severity levels, refer to *Table 7*. It can be observed that the construction method and conclusions of the double index model remain applicable to intersections with the same characteristics of the CLL. Although intersections with the same characteristics of the CLL have different specific geometric parameters, the conflict locations remain consistent at the same proportions corresponding to specific intersections.

Table 7 – Conflict locations and corresponding severity levels

Conflict location	Coordinate	Probability	Degree of conflict	PET	Degree of conflict	Original model conflict degree
9.624	(-4.05,6.095)	0.069	*Slight*	2.04	*Slight*	*Slight*
Pedestrian crosswalk	（-19.06,1.124）	0.260	*General*	1.96	*General*	*General*
Pedestrian crosswalk	(-19.01, -0.916)	0.124	*Slight*	2.48	*Slight*	*Slight*

Conflict location: refers to the distance between the location of the conflict and the crosswalk.

5.3 Discussion

To assess the safety implications of the CLL intersection, a case study is conducted at the Heping Avenue and Jinsui Avenue intersection in Xinxiang. By dividing the conflict zone in the intersection into two different areas, it can be determined that: (1) Zone A contains the crosswalk area, which extends for 2 meters along the direction of the vehicle. (2) Zone B is about 6 to 18 meters away from the crosswalk, which is characterised by the obvious lane-changing track of left-turning vehicles at the intersection.

The reasons for the model results can be explained as follows: (1) Zone A. In this area, left-turning vehicles from both the CLL and the conventional left-turn lane have just entered the intersection. Vehicles in the conventional left-turn lane are eager to choose a smaller turning radius and a closer distance to the receiving lane, resulting in a certain degree of turning driving behaviour and collection conflicts with left-turning vehicles in the CLL. In addition, at the pedestrian crosswalk, some non-motorised vehicles still choose to cross at the end of pedestrian green light time. At this time, when the main signal turns green, conflicts arise between the left-turning vehicles in the CLL and the conventional left-turn lane and the non-motorised vehicles. This generally leads to braking or deceleration by the contraflow left-turn vehicles, hindering their normal operation and causing safety issues. (2) Zone B. Within the intersection area, conflicts arise between the left-turning vehicles in the conventional left-turn lane and the CLL. Considering the trajectory of turning radius, drivers in the conventional left-turn lane typically attempt to change lanes to enter the normal driving trajectory of the CLL aiming for a closer left turn.

The traditional method of conflict computation is calculating the PET values of two vehicles after a conflict has occurred to determine the severity of the conflict. In the calculation of this method, there is a problem that the location of the vehicle conflict is different from that of calculating the conflict threshold. Researchers have to wait for the vehicle tracks to cross before they know the specific threshold. There is a certain delay. And in the process of the study, it was found that the position of calculating the conflict threshold of each pair of conflict is not fixed, which brings some inconvenience to the research. The model proposed in this study can take the conflict coordinate as input, calculate the severity of conflict when two vehicles arrive in the conflict coordinate. The result of the model has real-time characteristics. The research results are helpful for the vehicle to avoid in advance when it reaches the conflict point. Moreover, it helps to implement road safety measures within the intersection and is convenient for active safety management.

6. CONCLUSION

By incorporating the lateral indicators and the longitudinal ones of left-turning vehicles, we construct a comprehensive collection conflict model that considers both factors. This approach avoids the issue in previous traffic conflict safety studies, where vehicles were taken as points and their trajectories as lines. It offers a more realistic representation of the traffic conflict situations within the intersection.

By applying the principle of kinetic energy conservation, the potential destructive energy is used to measure the severity of traffic conflicts. This, in conjunction with the probability of collection conflicts, forms a double index left-turn conflict model. The conflict severity rate is then combined with traffic volume as an evaluation parameter.

At the pedestrian crosswalk and the entry section for left-turning vehicles into the intersection, a significant proportion of slight conflicts occur. During the operation of left-turning vehicles within the intersection, a substantial proportion is constituted by severe conflicts. The section where vehicles are about to complete the left turn and enter the exit lane is primarily associated with slight conflicts.

Considering that different design characteristics of intersections with different left-turn lanes may lead to varying driving behaviours, the proposed conflict model for left-turning vehicles did not take factors such as the length of the opening and signal timing into account. This will be considered in the next work.

In future studies, it can be considered to draw two white dashed lines from the contraflow and conventional left-turn lanes to the corresponding exit lanes. This white dashed line design has not been applied in the research intersection of this study. The occurrence of conflict may be reduced by this approach. The limitations of this study can be summarised as follows: in the process of constructing this model, there is a shortage of large vehicles. Considering that driving behaviours may vary among different vehicle types, more instances of large vehicles are needed to further refine the impact of vehicle types on traffic conflict.

ACKNOWLEDGEMENTS

This research was funded by the International Science and Technology Cooperation Program of the Henan Province, grant number 242102520030. This research was funded by the Foundation of Cultivation Programme for Young Backbone Teachers at the Henan University of Technology, grant number 21420157.

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针对借道左转交叉口的综合双指标左转冲突模型

摘要：

与常规交叉口相比，借道左转交叉口的左转车辆行驶过程具有不同的交通特征，本文主要聚焦于左转车辆进入接收车道的过程，以此来评估借道左转交叉口的安全性。基于左转车辆的到达率分析，呈现出借道左转车道的纵向冲突特征。在对车道进行微观区划的基础上，基于左转车辆的横向偏移构建了横向冲突特征。将纵向和横向特征进行相乘，得到多单元冲突指标。引入潜在碰撞指标，构建了双指标左转冲突模型。结果表明，冲突主要集中在两个区域：（1）在人行横道及其 2 米延伸范围内；（2）距离人行横道 6 至 18 米的范围内。针对交通冲突严重程度，所提模型具有较好的评估效果。