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Digital twin of highway entrances and exits: a traffic risk identification method

Changhe Liu
School of Highway
Chang'an University
Xi'an, China
liuchangh@yeah.net

Chi Zhang
School of Highway
Chang'an University
Xi'an, China
zhangchi@chd.edu.cn

Bo Wang
School of Highway
Chang'an University
Xi'an, China
wb1010110wb@chd.edu.cn

Zhongze Tang
School of Highway
Chang'an University
Xi'an, China
1378525350@qq.com

Zilong Xie
School of Highway
Chang'an University
Xi'an, China
2679696595@qq.com

***Abstract*—Aiming at the traffic risks at the entrances and exits of expressways, drones are used to obtain aerial video, and machine vision methods are used to extract traffic flow micro-data including driving trajectories and vehicle speeds, and segmented and integrated according to vehicle trajectories and speeds, and Prescan is used to build roads and driving trajectories. Model, and based on the driving simulation interface, the traffic trajectory simulation is realized in Vissim, which is used as a digital twin system of microscopic traffic flow at the entrance and exit sections of the expressway to realize the equivalent mapping of traffic flow at the entrance and exit sections. On this basis, the traffic conflict technology is further adopted to complete the identification of traffic risks at the entrance and exit of the expressway, and provide decision-making suggestions for safety improvement for the traffic safety management department.**

Keywords—digital twin, traffic conflict technology, freeway exit and entry area, Co-simulation, UAV aerial photography

I. INTRODUCTION

The concept of digital twin technology was born in 2003. With the rapid development of emerging technologies, its advantages in the fields of intelligent manufacturing, smart city, aerospace and other fields have been continuously revealed, and it has strong vitality. In the highway transportation industry, digital twins have also significantly improved the capabilities of traffic planning and management, emergency response and handling of emergencies by virtue of digital processing technology. Combined with the new generation of survey methods such as the Internet of Things, big data, cloud computing, and high-resolution remote sensing satellites, digital twin technology will also strongly promote the development of highway driving safety research [1-2].

At the same time, with the increasing density of highway network in my country, the construction quantity and service level of interchangeable interchanges as links of expressways are also increasing year by year. However, compared with other sections of the expressway, not only the speed difference of vehicles is larger, but also the traffic behavior is more complex, and the mutual interference between the acceleration and deceleration of vehicles and the lane-changing behavior is more serious, and the number of traffic accidents remains high all the year round. . Among the more than 10,000 traffic accidents in Yunnan Province in the four years from 2011 to 2015, the number of accidents that occurred at the entrance and exit sections accounted for 7% of the total number of accidents. Therefore, it is of great significance to study the traffic risks of the entrance and exit sections of the expressway and provide decision-making basis for the relevant departments to improve the safety level of expressway driving.

Domestic and foreign scholars have carried out certain researches on the driving risk of high-speed entrance and exit sections. Currently. Research methods usually include software simulation method [3], traffic conflict method [4, 5] and the combination of the two methods [6]. Among them, the software simulation method mainly calibrates the parameters of the highway entrance and exit model through the measured traffic trajectory data, road alignment data, etc., and then studies the influence of different risk factor variables on the driving risk level through the control variables. The selection of factors is limited, and the universality of model promotion is limited. For example, Guo Zhongyin [7] et al. used UC-win/Road to establish a simulated driving model of the entrance and exit sections, and studied the driving behavior characteristics such as speed and acceleration in this area. Zhang Xinhao [8] used VISSIM to study the entry road sections under different linear parameters and traffic flow parameters, and established a corresponding conflict prediction model. The traffic conflict rule is to obtain traffic conflict indicators such as TTC and PET by analyzing vehicle trajectories, and then determine the thresholds of different driving safety levels through cluster analysis and calculation of membership degree [9]. For example, Zheng Zhanji [10] and others proposed a traffic conflict prediction model based on the gap acceptance theory. To study the relationship between different driving behaviors and traffic accidents. In addition, some scholars [11] constructed a risk index based on the car-following and lane-changing behaviors of merging sections to evaluate the driving risk, or divided different traffic states according to the three-phase traffic flow theory as the evaluation basis [12], and then proposed driving based on the support vector machine technology. risk prediction model.

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To sum up, at present, researchers usually use simulation technology to calibrate the model, but the actual traffic flow state is usually described by the statistical characteristics of a large amount of driving data, and it is difficult to describe the accurate trajectory of each vehicle. Therefore, not only the universality of the evaluation model is difficult to guarantee, but also the accuracy should be further considered. To this end, this paper combines Prescan and Vissim micro-traffic flow digital twin systems, and uses drone video and gantry data before and after high-speed entrances and exits as input to identify the traffic risks of high-speed entrances and exits, and provide traffic management departments with safety decision-making. theoretical support.

II. Traffic Flow Perception of Entrance and Exit Sections

A. Data acquisition

When a vehicle enters or exits a highway, it usually experiences driving behaviors such as acceleration, deceleration and lane changing. The speed of the vehicle and its lateral position on the road surface will change greatly. In order to accurately obtain the traffic trajectory characteristics of the driving vehicle, unmanned aerial photography to obtain relevant data.

This method uses a DJI Mavic 2 Zoom drone to collect vehicle trajectories at the entrance and exit of the expressway, which is simple and convenient, and can be operated with a handheld remote control.

Since the UAV will be affected by wind and vibration when shooting in the air, after acquiring the video, this paper firstly performs graphic registration based on the SIFT algorithm to reduce the error in trajectory extraction. Its affine transformation relationship is shown in the following formula (1):

$$\begin{bmatrix} \check{x} \\ \check{y} \end{bmatrix} = k \begin{bmatrix} cos\theta & sin\theta \\ -sin\theta & cos\theta \end{bmatrix} \cdot \begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} \Delta x \\ \Delta y \end{bmatrix} \qquad (1)$$

In Equation (1), the point $(\check{x}, \check{y})$ on the reference image is (x, y) in the image to be registered, and k is the scale parameter. θ is the rotation angle. Δx and Δy are the translations of the two axes, respectively.

In order to realize the continuous tracking of the vehicle's driving trajectory, this paper uses Yolov5 to identify the composition of the vehicle, and tracks the vehicle's driving trajectory based on the Deepsort algorithm, and then obtains the relationship between the vehicle's driving speed and distance. By pre-calibrating the lane lines, the vehicle is relative to the lane lines. Finally, it is necessary to associate vehicle data with lane lines to determine the relative relationship of vehicle speed and driving trajectory to the road.The plane alignment of the road can be fitted and the pile-by-pile coordinates of the road design line can be output, and then the lateral displacement at the pile number k can be obtained by the following equation (2).

$$l_k = \sqrt{\left[\left(dm_{x_k} - carx_{ij}\right)^2 - \left(dm_{y_k} - cary_{ij}\right)^2\right]} \qquad (2)$$

In equation (2), l_k is the distance between the station k and the jth collection point of the ith vehicle. dm_{x_k} is the X coordinate of lane marker k. dm_{y_k} is the Y coordinate of lane marker k. $carx_{ij}$ is the X coordinate of the j collection point for the i car. $cary_{ij}$ is the Y coordinate of the jth collection point for the i car [13].

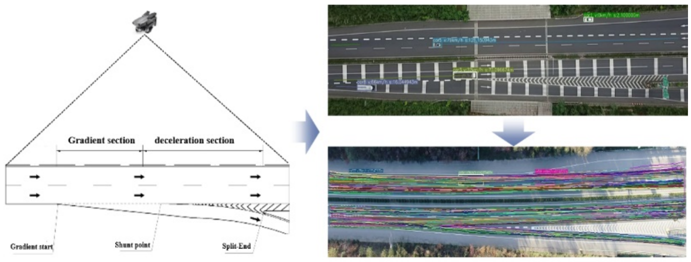

Fig. 1. Extraction of traffic trajectory parameters

B. Statistical analysis of data

TABLE I. Vehicle Trajectory Division of Entrance and Exit Sections

Segment Type	Vehicle Type	Driving Behavior	Speed		Acceleration
			Initial velocity	End speed	
Exit Section/ Entry Section	Truck/ Bus	Car Following	v_{fi}	v_{fe}	α_f
		....	…	…	…
		Changing Lanes	v_{li}	v_{le}	α_l
		....	…	…	…

In order to facilitate the input of vehicle trajectory in Prescan and achieve accurate restoration of the driving trajectory, after obtaining the vehicle trajectory and speed data, the vehicle type, road segment type, vehicle driving behavior, and vehicle following and changing can be collected according to Table 1. The division of acceleration and deceleration sections and constant speed sections under road behavior is shown in Table 1 above.

III. Digital Twin Platform Construction

Building a digital twin system for traffic flow perception and risk identification at the entrances and exits of expressways requires building a road model and a traffic trajectory model. This method is based on the Plugins Vissim Setting module of Prescan and the Driving Simulator module in Vissim to realize the co-simulation of Prescan and Vissim. Establish a road model and input the driving trajectory in Vissim, and complete the virtual simulation of the actual highway entrance and exit sections in Vissim, as shown in Figure 3 below.

A. Construction principle of co-simulation platform

PreScan is a software that creates a simulation environment for advanced driver assistance systems (ADAS) and smart vehicles. Prescan contains a large number of road models and vehicle types, which can be used to construct road and driving trajectory scenarios for different highway entry and exit sections. In addition, the software also includes various sensors such as lidar, ultrasonic radar, millimeter-wave radar, and video collector.

Vissim is a simulation tool mainly used to study the microscopic driving behavior, which can realize the traffic simulation of the road section according to the traffic composition of the starting and ending points and the road alignment conditions. It finally outputs parameter files for evaluating different traffic conditions for micro-vehicle following and lane changing behaviors. In addition, Vissim can be used to analyze traffic behavior under different traffic signal conditions.

In previous studies, Vissim is usually only based on different traffic flow densities and the ratio of traffic flow at the entrance and exit of the expressway. Although various traffic conflict parameters of the traffic flow can be output, the driving trajectory of a single vehicle in Vissim is not accurate. Therefore, the obtained conflict data tends to reflect the average level of the road section rather than the actual traffic conflict level of the road section.

Fig. 2. Digital twin system co-simulation platform

Therefore, the digital twin platform established by this method based on prescan and vissim has the following advantages:

- Based on the road entrance and exit template in Prescan, the expressway entrance and exit model can be quickly established, and the traffic trajectory in the collected video can be input.
- The simulation of the traffic trajectory can be completed synchronously through Vissim and the traffic trajectory file of the road section can be output, which is convenient for further extraction of traffic conflict parameters.
- This method extracts the driving trajectory of the highway entrance and exit sections based on the deep learning algorithm, and accurately copies it to the road model established by Prescan, which greatly improves the fidelity of the model simulation.
- On the basis of simulating and identifying traffic conflicts, the method can also simulate the traffic conflict scene after the implementation of traffic improvement measures based on the collected driving trajectory data, so as to provide data support for the decision-making of the traffic management department.

B. Steps to build a co-simulation platform

In order to realize the above-mentioned digital twin simulation platform, the method includes the following steps:

- Software and equipment requirements should be met first, including the installation of PreScan and Vissim, and a drone for stable shooting. It should be noted that Vissim should include the Driving simulator module.
- Develop a drone photography plan. In order to ensure the shooting effect, the environment should be kept at a normal level, and conditions such as bad weather and road closures should be avoided.
- Traffic trajectory processing and statistical analysis. The speed and form trajectory of the vehicle are extracted by the deep learning algorithm, and then the trajectory of each vehicle is divided according to Table 1.
- Build a road model and a vehicle trajectory model. Select the corresponding road segment template in Prescan, and change the number of lanes, width and lane line position of the main line according to the design of the road segment. Next, enter the vehicle trajectory according to the trajectory steps in Table 1.
- Vissim establishes the same trajectory model, and starts the Driving simulator module at the same time, and then realizes the synchronous simulation of Presacn and Vissim。
- Export the driving trajectory data (.trj file) of the highway entrance and exit sections through Vissim for subsequent traffic conflict parameter analysis。
- In addition, this method can also evaluate traffic risk improvement measures on the vissim platform based on the currently collected traffic flow density, flow, and speed.

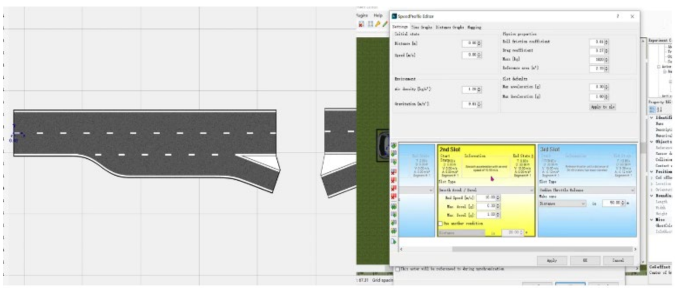

Fig. 3. Prescan builds a road model and inputs

IV. TRAFFIC CONFLICT RECOGNITION

Traffic conflict technology is widely used in traffic risk assessment [14, 15], and the conflict data is also easy to obtain according to the aforementioned simulation platform, so this method uses traffic technology to identify traffic risks in highway entrance and exit sections.

Among them, the indirect safety assessment model (SSAM) is a traffic safety assessment software developed by the Federal Highway Administration (FHWA), which can calculate traffic conflict parameters, based on the trajectory file (.trj file) exported by Vissim, including distance to collision time (TTC), post-occupancy time (PET), initial deceleration (DR), maximum speed (MaxS) and relative speed (DeltaS) six items.

This method judges whether the vehicle has collision risk according to TTC and PET. In addition, according to the conflict angle β of the output, the conflict can also be divided into three types: positive conflict, lane change conflict and rear-end conflict. Referring to related studies [16, 17], the TTC threshold is set to 1.5s, the PET threshold is set to 5.0s, and the traffic conflict angle threshold is the default value of SSAM.

$$\mathrm{TTC} = \frac{X_{i-1} - X_i - L_{i-1}}{V_i - V_{i-1}} \tag{3}$$

$$\mathrm{Pet} = t_2 - t_1 \tag{4}$$

Among them, X_{i-1}、 V_{i-1} are the position and speed of the preceding vehicle; X_i、 V_i represent the speed of the following vehicle; L_{i-1} is the length of the preceding vehicle; t_1、 t_2 are respectively the time when the front and rear vehicles pass the conflicting position.

The speed difference between vehicles is the decisive factor leading to vehicle collision. Therefore, for areas with serious traffic conflicts, corresponding speed limit measures should be taken, including setting up longitudinal deceleration markings, prompting and guiding drivers to slow down. In addition to the speed limit signs, exit warning signs should be set up in advance on the inter-connected exit sections to guide the traffic flow to change lanes in advance.

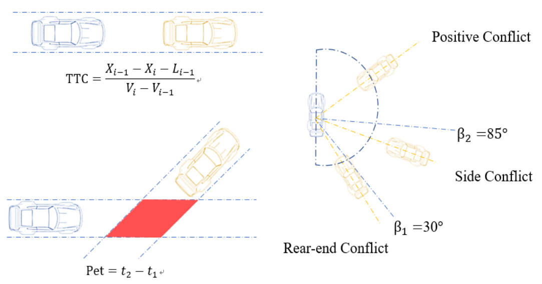

Fig. 4. Traffic conflict type diagram

V. Conclusion

This paper proposes a digital twin framework that extracts traffic trajectories based on deep learning algorithms, and then realizes traffic risk identification at highway entrances and exits through co-simulation of Prescan and Vissim. The method is simple and effective, and can accurately restore the road model and driving trajectory, and identify the existing traffic conflicts. In addition, this method can also be used in the simulation of improvement measures for this road section.

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References

[1] Zhang Bo, Yang Xinrang. Digital Twin in China [J]. China Highway , 2022 , (4): 30 - 33.

[2] Yang Wenhui. Study On BIM Technology Of Self-Anchored Suspension Bridge Forlifecycle Mangement [D]. Southwest Jiaotong University.

[3] Ding Yue. Study on Traffic Flow Characteristics of Interchange Merging-Areas Basing on Traffic Safety [D]. Southeast University, 2017.

[4] Zhao Xiaoyue , Wang Pan , Zhu Shunying , et al. Spatial Distribution of Traffic Conflicts in Interchange Merging Area Based onVideo Recognition[J]. Journal of Highway and Transportation Research and Developmen , 2021, 38(5): 90-99.

[5] Li, Shen, Xiang, et al. IJERPH, Vol. 13, Pages 1157: Crash Risk Prediction Modeling Based on the Traffic Conflict Technique and a Microscopic Simulation for Freeway Interchange Merging Areas. 2016.

[6] Chen Qian. Study on Traffic Conflict Mechanism in Diverging and Merging Segment of Expressway Interchange [D]. Hefei University of Technology, 2019. DOI: 10.27101/d. cnki. ghfgu. 2019. 000364.

[7] Guo Zhongyin, Wan Haifeng, Zhao Yi, et al. Driving Simulation Study on Speed-change Lanes of the Multi-lane Freeway Interchange [J]. Procedia-Social and Behavioral Sciences, 2013, 96: 60-69.

[8] Zhang Xinhao. Research on Traffic Conflict Prediction and Safety Assessment Method in Merging Area of Expressway Interchange[D]. Chang'an University , 2021. DOI: 10. 26976/d. cnki. gchau. 2021. 000605.

[9] Zhang Xin, Zhang and Weihua, Feng Zhongxiang, et al. Traffic Safety Evaluation of Expressway Confluence Area Based on Traffic Conflict Technology [J]. Journal of Safety and Environment, 2020 , 27(4): 174-179.

[10] Zheng Zhanji, Xiang Qiaojun, Li Han, et al. Model for predicting traffic conflict in interchange diverging area [J]. China Safety Science Journa, 2018, 28(06): 85-90. DOI: 10.16265/j. cnki. issn1003-3033. 2018.06. 015.

[11] Zhang Xiaodong, Guo Zhongyin, Gao Jianping, et al.Theoretical analysis on the safety of the merging area at the entrance of the expressway[J]. Journal of Chongqing Jiaotong University, 2006 (01): 99-102+106.

[12] Liu Tong. Research on the relationship between traffic flow operation status and traffic safety in expressway merging areas based on trajectory data [D]. Southeast University, 2021. DOI: 10. 27014/d. cnki gdnau . 2021. 003462.

[13] Zhang Chi, Tang Zhongze, Zhang Min, Wang Bo, Hou Lei. Developing a More Reliable Aerial Photography-Based Method for Acquiring Freeway Traffic Data[J]. Remote Sensing,2022,14(9).

[14] IBITOYE B A, ABDULWAHAB R, and BAMIDELE A. Evaluation of Collision Potential at Four-legged Unsignalized Intersection Using Traffic Conflict Technique [J]. European Journal of Engineering Research and Science, 2017, 2 (3): 1-4.

[15] Zhu Shunying, Jiang Ruoxi, Wang Hong, et al. Review of Research on Traffic Conflict Techniques [J]. China Journal of Highway and Transport, 2020, 33(2): 15-33.

[16] Gettman D, Pu L, Sayed T, et al. Surr ogate Safety Assessment Model and Validation (SSAM): FHWA HRT-08-049 [R].Washington, DC: Department of Transportation, 2008.

[17] Sayed T , Brown G, and Navin F. Simulation of traffic conflicts at unsignalized intersections with TSC-Sim[J]. Accident Analysis &Prevention, 1994 ,26(5): 593-607.