Global Science Publishing

JCMEA

Journal of Computational Methods in Engineering Applications
https://ojs.sgsci.org/journals/jcmea

Article

Safety Evaluation of Traffic System with Historical Data Based on Markov Process and Deep-Reinforcement Learning

Wenjun Dai

Shenzhen Urban Transport Planning Center Co., Ltd, Shenzhen 518000, China

Abstract: This study introduces a comprehensive framework for discerning and enhancing traffic system safety through a multifaceted approach that integrates Markov processes and deep reinforcement learning (DRL). The foundation of this framework lies in the establishment of key safety evaluation metrics, predicated upon a thorough survey of historical data and pertinent regulations. These metrics, once identified, are systematically scored within discrete nodes, ensuring a nuanced and precise assessment. Subsequently, areas displaying lower scores are pinpointed, prompting the implementation of tailored improvement strategies aimed at mitigating identified shortcomings. This process culminates in the rigorous testing of the efficacy of these interventions, effectuated through a comparative analysis of the established scores pre- and post-improvement. By leveraging the synergy between Markov processes and DRL, this approach not only gauges the system's current safety status but also enables the formulation and execution of targeted enhancements. This framework forms an integral step toward achieving a traffic system that is both responsive and resilient, ultimately fostering a safer and more efficient urban mobility landscape.

Keywords: traffic systems; safety; deep learning; reinforcement learning; markov process

1. Introduction

With the rapid development of city, there will be more and more buildings, people and vehicles in traffic systems. Large traffic demand leads traffic safety challenges to traffic systems. In specific, with the increasing of people and vehicles, more traffic fundamental facilities and reasonable traffic design will be needed to improve the reliability and safety of the traffic system [1–3].

This paper identifies the key safety problems based on accident statistical data in Shenzhen and evaluate the safety condition of this traffic system. For evaluation indicator, reference to AHP (Analytic Hierarchy Process), digitalize factors related to traffic safety and get the safety score of traffic system. When the safety problems are found, use specific measures to improve them and test the effect by safety score comparison.

A typical region was chosen to research. The research region is located in Nanshan Overseas Chinese Town area of Nanshan District, Shenzhen, which is surrounded by Shahe east road, Xiangshan west street, Shahe street and Xinzhong road (shown in Figures 1 and 2).

Received: 11 August 2021; Accepted: 28 September 2021.

* Corresponding: Wenjun Dai (dd286382@gmail.com)

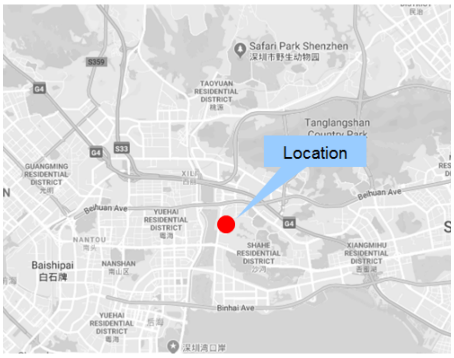

Figure 1. Location of research region.

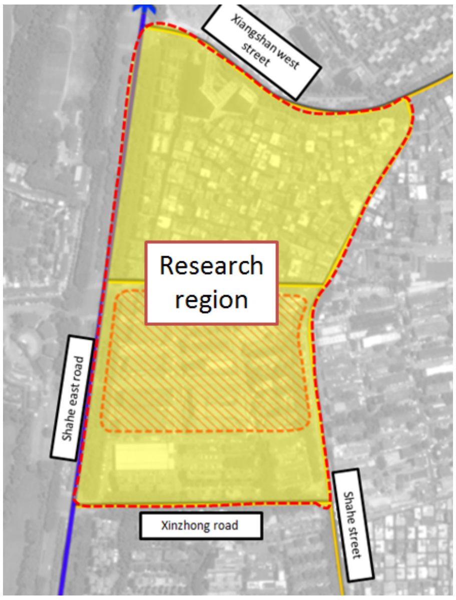

Figure 2. Boundary of research region.

2. Methodology

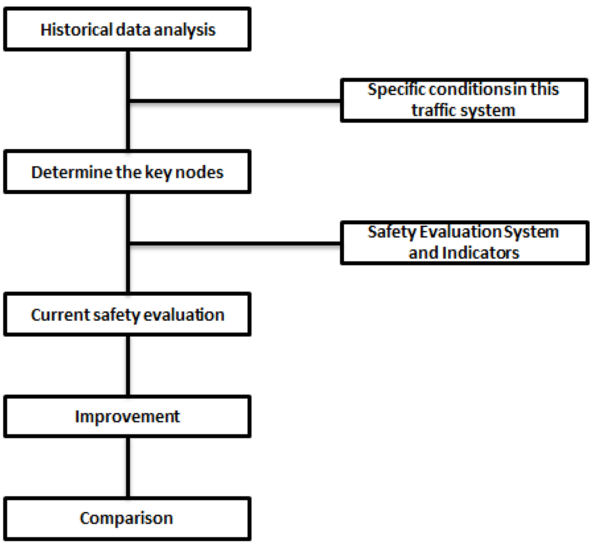

Figure 3. Framework of safety evaluation and improvement.

According to historical statistics of traffic accidents, identifying the main causes of traffic accidents. And combine with specific conditions and network in this research region to determine the key nodes of safety problems [4–7]. For safety evaluation, reference to safety researches in transport industry before, introducing traffic safety evaluation system in this research and scoring the safety of the traffic system [8–11]. According to evaluation, use specific measures to improve the safety of those key nodes and test the improvement effect by comparing the score before and after improvement (shown in Figure 3).

For traffic safety evaluation system, reference to the research "Safety evaluation on slow traffic facilities around an intersection" and "Specification for design of intersections on urban roads" (GB50647-2011), in this research, chooses 7 specific indicators of facilities to evaluate the safety. And in each indicator, use 3 scoring criteria to determine the score of this indicator. As shown in Figure 4.

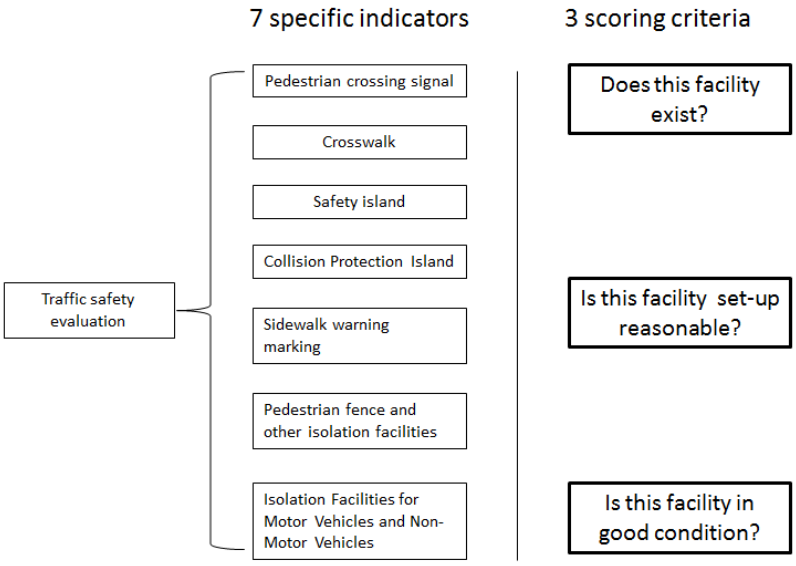

Figure 4. Traffic safety evaluation framework.

To digitize the evaluation results, combine with expert scoring method and references, determine the weight of indicators and scoring criteria. As shown in Table 1 and 2.

Table 1. Weight of 7 indicators.

Indicators	Weight
Pedestrian crossing signal	0.18
Crosswalk	0.16
Safety island	0.12
Collision protection Island	0.11
Sidewalk warning marking	0.13
Pedestrian fence and other isolation facilities	0.14
Isolation facilities for motor vehicles and non-motor vehicles	0.16

Table 2. Weight of 3 scoring criteria.

Scoring criteria	Weight
Does this facility exist?	0.2
Is this facility set-up reasonable?	0.4
Is this facility in good condition?	0.4

For each indicator's score, showed below (maximum 100) (shown in Figure 5).

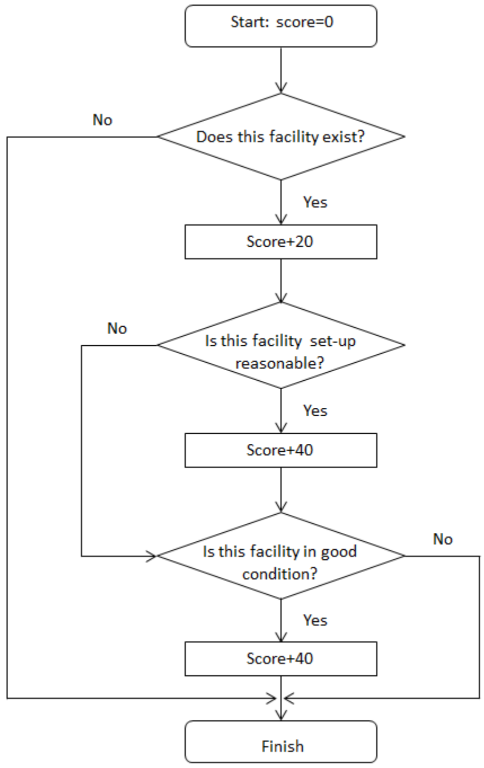

Figure 5. Scoring flow chart.

When all indicators' score are calculated, multiply the corresponding weight of indicators, and then get the sum of them. The number is the score of the node. Details showed below (shown in Table 3).

Table 3. Calculation of node safety score.

Indicators	Weight	Score of indicators	Score of the node
Pedestrian crossing signal	0.18	a	0.18a+0.16b+0.12c+0.11d+0.13e+0.14f+0.16g
Crosswalk	0.16	b	
Safety island	0.12	c	
Collision protection Island	0.11	d	
Sidewalk warning marking	0.13	e	
Pedestrian fence and other isolation facilities	0.14	f	
Isolation facilities for motor vehicles and non-motor vehicles	0.16	g	

3. Historical data analysis

According to the 2012 Annual Report of Road Traffic Accidents Statistics, 4727000 road traffic accidents were reported nationwide, an increase of 503000 over the same period last year, an increase of 11.9%. Among them, 204196 road traffic accidents involving casualties resulted in 59997 deaths, 224327 injuries and 1.17 billion yuan of direct property losses. Among them, 10464 accidents related to non-motor vehicle violations accounted for 5.13% of the total, with 1488 deaths, 11655 injuries and 19.57 million direct property losses, accounting for 2.48%, 5.91% and 1.67% of the total, respectively; 1908 accidents related to pedestrian-driver violations accounted for 0.93% of the total, with 1016 deaths and injuries. The total number was 1052, with direct property losses of 11.28 million yuan, accounting for 1.07%, 0.47% and 0.96% of the total, respectively.

According to statistical data of Shenzhen traffic police department, as of 2017, pedestrians and non-motor vehicles were the main victims of traffic accidents in Shenzhen, accounting for about 70%. And the proportion of accident types is showed below (shown in Figure 6).

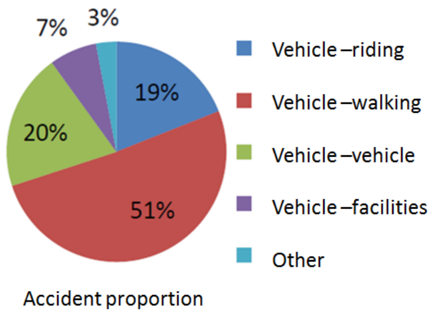

Figure 6. Proportion of accident types.

In this chart, accidents between vehicle and walking account for the largest proportion, reaches 51%. And the proportion of vehicle-riding accidents is 19%.

Through this data, the 70% accidents happened in Shenzhen involved in walking and riding people. And combine with the situation that pedestrians and non-motor vehicles have a high mortality rate in traffic accidents, the safety of walking and riding people in traffic system is urgently needs to be improved.

In traffic system, intersections are the most intertwined nodes of motor vehicles, non-motor vehicles and pedestrians, they are the places where traffic accidents happen frequently.

Therefore, this research focused on the safety at intersections, evaluate the safety facilities at intersections and improve them.

4. Determine the research nodes

Currently, in research region, there are 6 intersections. As along Shahe East Road, traffic facilities at signalized intersections are completed, and pedestrians and motor vehicles are organized in a relatively orderly manner, thus, for safety part, this research focus on 3 intersections on Shahe Street.

Therefore, determine the key nodes (shown in Figure 7).

(1) Shahe Street- Xinzhong Road

(2) Shahe Street- Xintang Road

(3) Shahe Street- Xiangshan West Street

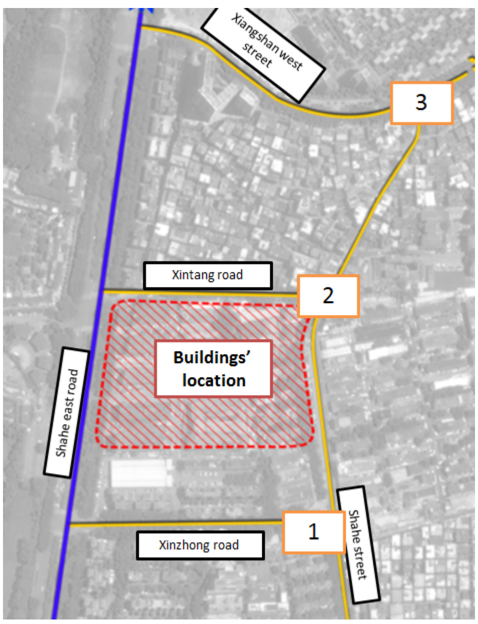

Figure 7. Location of key nodes (intersections).

5. Current safety evaluation

5.1. Evaluation of node 1 (Shahe Street- Xinzhong Road)

Figure 8. Current condition of Shahe Street- Xinzhong Road.

In Figure 8, for the first indicator (Pedestrian crossing signal), there are not signal lights at this node. In “Figure 5 Scoring flow chart”, the first question’s answer is “No”. Thus, the score of first indicator is 0.

For the second indicator (Crosswalk), there are 2 crosswalks at this node. In “Figure 5 Scoring flow chart”, the first question’s answer is “Yes” (score+20); the second question’s answer is “No”, because there are still 2 approaches without crosswalk; the third question’s answer is “Yes” (score+40). Thus, the score of second indicator is 60.

Use this method to calculate other indicators’ score, and the solution is (0, 60, 0, 0, 60, 20, 20). After that, the score of this node can be calculated, and the score is 23.4. As shown in Table 4.

Table 4. Score of node 1 (Shahe Street- Xinzhong Road).

Indicators	Weight	Score of indicators	Score of the node
Pedestrian crossing signal	0.18	0	
Crosswalk	0.16	60	
Safety island	0.12	0	
Collision protection Island	0.11	0	23.4
Sidewalk warning marking	0.13	60	
Pedestrian fence and other isolation facilities	0.14	20	
Isolation facilities for motor vehicles and non-motor vehicles	0.16	20	

5.2. Evaluation of node 2 (Shahe Street- Xintang Road)

Currently, in this node, there is no pedestrian crossing signal. There are warning signs for pedestrian crossings and sidewalks, but in some areas, pedestrian space is occupied and isolation facilities for pedestrians, non-motor vehicles and motor vehicles are inadequate (shown in Figure 9).

Figure 9. Current condition of Shahe Street- Xintang Road.

Use the same score method to evaluate each indicator in this node and do calculation, and the score is 15.4. Details are shown in Table 5 below.

Table 5. Score of node 2 (Shahe Street- Xintang Road).

Indicators	Weight	Score of indicators	Score of the node
Pedestrian crossing signal	0.18	0	
Crosswalk	0.16	60	
Safety island	0.12	0	
Collision protection Island	0.11	0	15.4
Sidewalk warning marking	0.13	20	
Pedestrian fence and other isolation facilities	0.14	0	
Isolation facilities for motor vehicles and non-motor vehicles	0.16	20	

5.3. Evaluation of node 3 (Shahe Street- Xiangshan West Street)

Figure 10. Current condition of Shahe Street- Xiangshan West Street.

Currently, in this node, there is no pedestrian crossing signal. The crosswalk is relatively perfect, but the zebra crossing is not clear. In Xiangshan West Street, the isolation facilities for sidewalks, motor vehicles and non-motor vehicles are good, but in Shahe Street, the isolation facilities are insufficient. And the safety warning signs are insufficient in this node (shown in Figure 10).

Use the same score method to evaluate each indicator in this node and do calculation, and the score is 30.2. Details are shown in Table 6 below.

Table 6. Score of node 3 (Xiangshan West Street).

Indicators	Weight	Score of indicators	Score of the node
Pedestrian crossing signal	0.18	0	
Crosswalk	0.16	60	
Safety island	0.12	0	
Collision protection Island	0.11	0	30.2
Sidewalk warning marking	0.13	20	
Pedestrian fence and other isolation facilities	0.14	60	
Isolation facilities for motor vehicles and non-motor vehicles	0.16	60	

6. Improvement

6.1. Improvement of node 1 and node 2 (Shahe Street- Xinzhong Road and Shahe Street- Xintang Road)

According to indicators score in 5.5, the main reason for the low safety evaluation score of node 1&2 is that the isolation facilities for pedestrians, motor vehicles and non-motor vehicles are not enough. At the same time, the unreasonable allocation of road space is the main limitation to set safety facilities.

Analysis: Node 1&2 are both located in Shahe Street, according to current topographic map, the space for pedestrian and non-motor vehicles in this street is only 2 meters. As shown in Figure 11.

Figure 11. Current sidewalk in Shahe Street.

However, there are 3 vehicle lanes in Shahe Street. According to investigation, the number of vehicles on this street is about 300 pcu/h. 3 vehicle lanes capacity is much more lager than this volume (4800 pcu/h in theory).

6.1.1. Recommendation

(1) As the number of cars is not too many on Shahe street, more space should be divided to walking and riding people. Change 3vehicle lanes to 2 and set exclusive lanes for walking and riding people. The width of each vehicle lane is 3 meters, for walking lane are 1.5 meters and 3 meters for riding lane. The recommended road sections are as follows and as checked in topographic map, the space is enough for this road sections (shown in Figure 12).

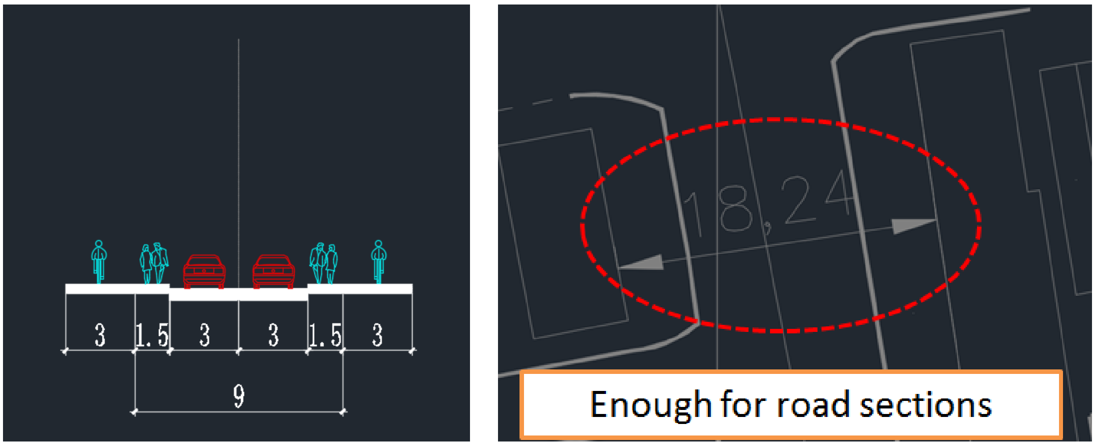

Figure 12. Recommended road section of Shahe street.

(2) As the road space is enough, more isolation facilities can be set in these nodes. Such as pedestrian fence, isolation facilities for motor vehicles and non-motor vehicles (shown in Figure 13).

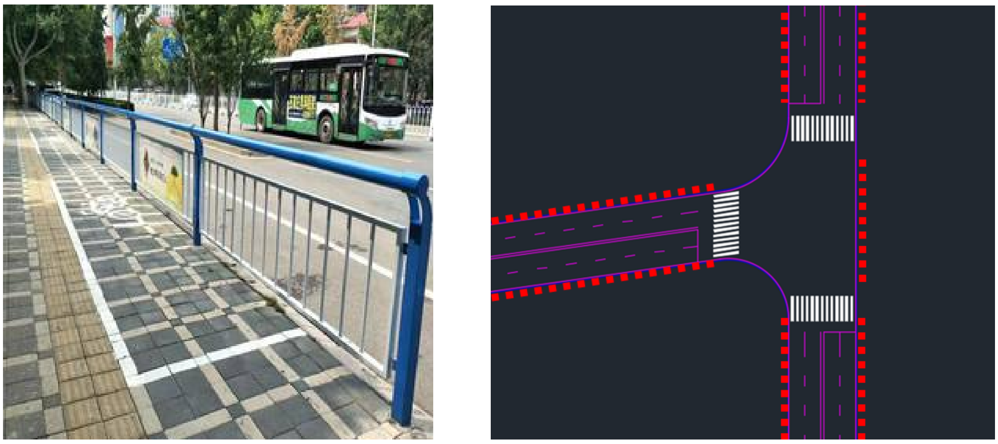

Figure 13. Isolation setting diagram.

6.2. Improvement of node 3 (Shahe Street- Xiangshan West Street)

Analysis: For node 3, the main problem is lack of sidewalk warning markings. The isolation facilities in this node are relatively completed. And the zebra crossing is not clear.

6.2.1. Recommendation

(1) Re-draw zebra crossings on the road to make it clearer. At the same time, pedestrian and vehicle lane signs need to be set at the node (shown in Figure 14).

Figure 14. Example of signs.

(2) As Xiangshan West Street is secondary road, the speed control is important. What's more, according to statistics of Shenzhen traffic police department, more than one third of traffic accidents involve in over speeding factors. According to chart below, when accident happened, higher speeds higher death rate. And when the speed exceeds 30 km/h, the possibility of vehicle-walking collision injury increases rapidly. Thus, in this node, setting speed hump and speed control signs in front of crosswalk to limit vehicles speed under 30 km/h (shown in Figures 15 and 16).

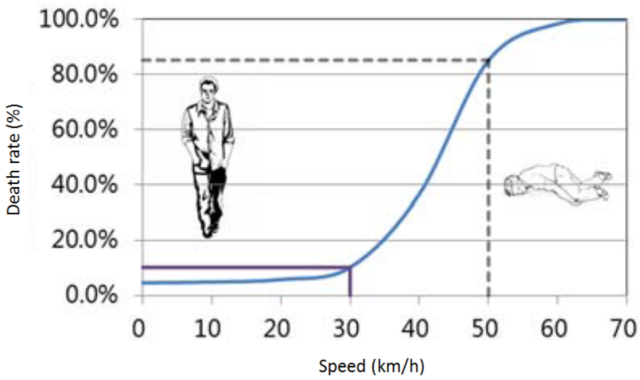

Figure 15. Graph of the relationship between speed and mortality.

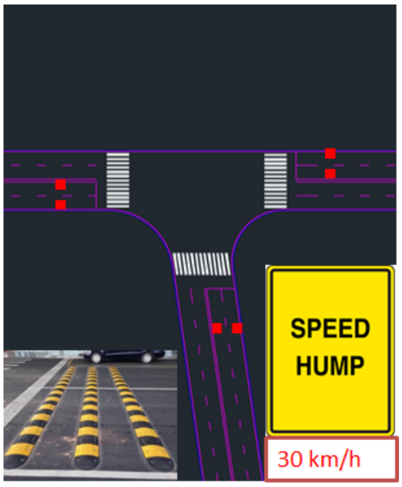

Figure 16. Setting speed limiting facilities.

7. Improvement effect testing

After improvement, calculate the score of each node again. Use the same method defined in 5.4. The results are shown in Tables 7–9 below.

Table 7. Score of node 1(after improvement).

Indicators	Weight	Score of indicators	Score of the node
Pedestrian crossing signal	0.18	0	
Crosswalk	0.16	60	
Safety island	0.12	0	
Collision protection Island	0.11	0	47.4
Sidewalk warning marking	0.13	60	
Pedestrian fence and other isolation facilities	0.14	100	
Isolation facilities for motor vehicles and non-motor vehicles	0.16	100	

Table 8. Score of node 2 (after improvement).

Indicators	Weight	Score of indicators	Score of the node
Pedestrian crossing signal	0.18	0	
Crosswalk	0.16	60	
Safety island	0.12	0	
Collision protection Island	0.11	0	42.2
Sidewalk warning marking	0.13	20	
Pedestrian fence and other isolation facilities	0.14	100	
Isolation facilities for motor vehicles and non-motor vehicles	0.16	100	

Table 9. Score of node 3(after improvement).

Indicators	Weight	Score of indicators	Score of the node
Pedestrian crossing signal	0.18	0	
Crosswalk	0.16	60	
Safety island	0.12	0	
Collision protection Island	0.11	0	40.6
Sidewalk warning marking	0.13	100	
Pedestrian fence and other isolation facilities	0.14	60	
Isolation facilities for motor vehicles and non-motor vehicles	0.16	60	

For improvement effect testing, compare the score of each node before and after improvement. As shown in Table 10 below.

Table 10. Comparison of score before and after improvement.

Node	Score before improvement	Score after improvement
Shahe Street- Xinzhong Road	23.4	47.4
Shahe Street- Xintang Road	15.4	42.2
Shahe Street- Xiangshan West Street	30.2	40.6

In this table, the safety score of each node has a significant promotion which means the safety has been improved.

8. Conclusion

The purpose of this research is to improvement the safety of a traffic system. Referencing to historical statistics of traffic accidents, identifying the main causes of traffic accidents. And combine with specific conditions and network in this research region to determine the key nodes of safety problems. Then establish safety evaluation system by reference to safety researches in transport industry before. After that, according to evaluation, use specific measures to improve the safety of those key nodes and test the improvement effect by comparing the score before and after improvement.

In conclusion, the amalgamation of Markov processes and deep reinforcement learning presents a formidable paradigm for appraising and fortifying the safety of complex traffic systems. By articulating a comprehensive framework, this study has underscored the importance of integrating historical data, rigorous metrics, and targeted interventions to bolster safety measures effectively [12–18]. The nuanced and systematic scoring system enables a granular assessment, highlighting specific areas necessitating improvement. This approach not only facilitates the identification of pertinent safety parameters but also empowers the implementation of bespoke enhancement strategies tailored to the unique exigencies of diverse traffic nodes. Furthermore, the testing and validation phase illuminates the tangible impact of these interventions, culminating in a substantive appraisal of the efficacy of the proposed improvements. This integrated framework does not merely evaluate safety retrospectively but acts as a dynamic tool, capable of guiding proactive measures to mitigate risks within the traffic ecosystem. As urban centers continue to grapple with burgeoning mobility challenges, this framework stands as a potent instrument for cultivating adaptive and secure transportation infrastructures. Ultimately, the holistic integration of Markov processes and deep reinforcement learning [19–25] advances the imperative goal of fostering robust, resilient, and safe traffic systems, constituting a pivotal stride towards sustainable urban mobility.

Funding

Not applicable.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

Data is available upon request from the corresponding authors.

Conflicts of Interest

The author declares no conflict of interest.

Reference

1 Zhu S. Safety Evaluation on Slow Traffic Facilities Around an Intersection. *Journal of Huaiyin Institute of Technology* 2014; **22**: 30–03.

2 Austin PC. Are (the Log-Odds of) Hospital Mortality Rates Normally Distributed? Implications for Studying Variations in Outcomes of Medical Care. *Journal of Evaluation in Clinical Practice* 2009; **15**: 514–523.

3 Park B-J, Lord D, Lee C. Finite Mixture Modeling for Vehicle Crash Data with Application to Hotspot Identification. *Accident Analysis and Prevention* 214; **71**: 319–326.

4 Sun C, Li W, Shao Y. Fault Tolerant Design and Management of Urban Road Traffic Safety. *Journal of Papers on Urban Traffic Planning in China* 2017; **15**: 199–342.

5 AASHTO. *Highway Safety Manual, 1st ed.*; American Association of State Highway and Transportation Officials (AASHTO): Washington, DC, USA, 2010.

6 Elvik R. New Approach to Accident Analysis for Hazardous Road Locations. *Transportation Research Record* 2006; **1953**(**1**): 50–55.

7 Lyon C, Gotts B, Wong W, Persaud B. Comparison of Alternative Methods for Identifying Sites with High Proportion of Specific Accident Types. *Transportation Research Record* 2007; **2019**(**1**): 212–218.

8 Mannering FL, Bhat CR. Analytic Methods in Accident Research: Methodological Frontier and Future Directions. *Analytic Methods in Accident Research* 2014; **1**: 1–22.

9 Milton JC, Shankar VN, Mannering FL. Highway Accident Severities and the Mixed Logit Model: An Exploratory Empirical Analysis. *Accident Analysis and Prevention* 2008; **40**: 260–266.

10 Miranda-Moreno LF, Fu L, Ukkusuri SV, Lord D. How to Incorporate Accident Severity and Vehicle Occupancy into the Hot Spot Identification Process?. *Transportation Research Record* 2009; **2102**: 53–60.

11 Xie K, Wang X, Ozbay K, Yang H. Crash Frequency Modeling for Signalized Intersections in a High-

Density Urban Road Network. *Analytic Methods in Accident Research* 2014; **2**: 39251.

12 Shafieezadeh A, Wang Z. A Parallel Learning Strategy for Adaptive Kriging-Based Reliability Analysis Methods. 13th International Conference on Applications of Statistics and Probability in Civil Engineering, Seoul, South Korea, 26–30 May 2019.

13 Darestani YM, Wang Z, Shafieezadeh A. Wind Reliability of Transmission Line Models using Kriging-Based Methods. 13th International Conference on Applications of Statistics and Probability in Civil Engineering ICASP13, Seoul, South Korea, 26–30 May 2019.

14 Zhang C, Wang Z, Shafieezadeh A. Value of Information Analysis via Active Learning and Knowledge Sharing in Error-Controlled Adaptive Kriging. *IEEE Access* 2020; **8**: 51021–51034.

15 Wang Z, Shafieezadeh A. REAK: Reliability Analysis Through Error Rate-Based Adaptive Kriging. *Reliability Engineering & System Safety* 2019; **182**: 33–45.

16 Wang Z, Shafieezadeh A. ESC: an Efficient Error-Based Stopping Criterion for Kriging-Based Reliability Analysis Methods. *Struct Multidisc Optim* 2019; **59**(**5**): 1621–1637.

17 Wang Z, Shafieezadeh A. Highly Efficient Bayesian Updating Using Metamodels: An Adaptive Kriging-Based Approach. *Structural Safety* 2020; **84**: 101915.

18 Wang Z, Shafieezadeh A. On Confidence Intervals for Failure Probability Estimates in Kriging-Based Reliability Analysis. *Reliability Engineering & System Safety* 2020; **196**: 106758.

19 Wang Z, Shafieezadeh A. Real-Time High-Fidelity Reliability Updating With Equality Information Using Adaptive Kriging. *Reliability Engineering & System Safety* 2020; **195**: 106735.

20 Wang Z, Shafieezadeh A. Metamodel-Based Subset Simulation Adaptable to Target Computational Capacities: the Case for High-Dimensional and Rare Event Reliability Analysis. *Structural Multidisciplinary Optimization* 2021; **64**: 649–675.

21 Zhang C, Wang Z, Shafieezadeh A. Error Quantification and Control for Adaptive Kriging-Based Reliability Updating with Equality Information. *Reliability Engineering & System Safety* 2021; **207**: 107323.

22 Rahimi M, Wang Z, Shafieezadeh A, Wood D, Kubatko EJ. An Adaptive Kriging-Based Approach with Weakly Stationary Random Fields for Soil Slope Reliability Analysis. *Geo-Congress* 2019; 148–157. DOI: 10.1061/9780784482155.015.

23 Luo Z, Xu H, Chen F. Audio Sentiment Analysis by Heterogeneous Signal Features Learned from Utterance-Based Parallel Neural Network. Proceedings of the 2nd Workshop on Affective Content Analysis (AffCon 2019) Co-Located with Thirty-Third AAAI Conference on Artificial Intelligence (AAAI 2019), Honolulu, HI, USA, January 27 2019.

24 Chen F, Luo Z, Xu Y, Ke D. Complementary Fusion of Multi-Features and Multi-Modalities in Sentiment Analysis. AAAI-2020 Workshop on Affective Content Analysis, New York, NY, USA, 7 February 2020.

25 Luo Z, Zeng X, Bao Z, Xu M. Deep Learning-Based Strategy for Macromolecules Classification with Imbalanced Data from Cellular Electron Cryotomography. *2*019 International Joint Conference on Neural Networks (IJCNN), Budapest, Hungary, 14–19 July 2019.