Risk Analysis on Maintenance of Freeway workzone: an Approach based on Apriori-LEC

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Abstract. In order to reduce the operation risks of freeway maintenance, the paper used Apriori algorithm method to explore the factors with strong interconnection in the deploy and control, construction process that affect operational safety. An analysis model for the deploy and control, construction was established based on improved LEC (operating condition assessment method, L: likelihood, E: exposure, C: consequence) method; The model was used to calculate and analyze the risk level of a maintenance workzone, and the risk value is between 47-56, which is low and consistent with the safety situation investigated on-site in the maintenance workzone. The model can effectively pinpoint key risk factors affecting the safety of freeway maintenance workzone and be used to conduct quantitative risk assessment, so the study can provide theoretical guidance for improving the safety of freeway maintenance workzone.

Keywords: Freeway maintenance workzone; Deploy and control; Construction; Risk analysis

1 Introduction

With the increase of freeway maintenance work volume year by year, the safety problem in maintenance workzone is more and more serious. How to accurately identify the risk factors of maintenance workzone, determine the key risk factors and take measures to reduce the risk has become the primary task of current research on the safety of maintenance workzone. About risk research on maintenance workzone, references [1-3] conducted an analysis of the key risk factors, while references [4-10] explored the risk assessment methodologies. The workzone safety is studied mainly by analyzing the traffic situation outside the maintenance workzone, and lake of research based on internal problems of workzone. This paper analyzes various risk

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factors based on the internal problems of maintenance operations and establishes a risk assessment model to calculate the overall risk level of maintenance operations. The paper conducts analysis and evaluation on the risk factors based on actual problems, which is a supplement to the existing theory and also has great practical guiding significance.

2 Risk factor analysis

The daily maintenance workflow of freeway is shown in Figure 1. According to the tracking investigation and data statistical analysis of field maintenance operations, it is found that risk problems occur mainly in the processes of deploy and control, construction.

The risk factors of deploy and control mainly include section length, signs, cone markers, and control personnel, etc. The risk factors of section length refer to the fact that the actual length of each section is lower than that specified in the control plan, and in serious cases, the downstream transition zone and termination zone are not controlled. The risk of signage refers to the wrong type of signage, inaccurate placement, tilting and tipping of signage due to poor fixation. The risk of cone markers includes the poor line shape and tipping of cone caused by the worker's negligence, delay of inspection and also influenced by traffic flow, as well as the common problem of too large distance between cones. The risk of deploy and control personnel includes the absence of traffic guides on duty or no traffic guidance behavior, and the wrong order of deploy and control, collection, etc. The factors (X_i, i=1,2,3...) are shown in Table1.

Table 1. Risk Factors of Deploy and Control

Type	risk factors		Code	Type	risk factors		Code
Warning Area	Length	Insufficient length	X1		Length	Missing signage	X17
	Signage	Missing signage	X2		Signage	Signage in wrong position	X18
		Insufficient sign spacing	X3		Disarming	The time of collection and control is late	X19
		Signage in wrong position	X4		Disarming	No control	X20
		Sign tipping over	X5	Deploy and control	Anti-collision vehicle	Wrong order	X21
		Inadequate sign height	X6			No collision avoidance vehicle	X22
		Inadequate sign stability	X7		Anti-collision vehicle	The lights of collision avoidance vehicle are not on	X23
Upstream transition	Length	Insufficient length	X8		Traffic Guides	No traffic guide	X24
		Missing signage	X9			Personnel are not on duty	X25

area		Insufficient sign spacing	X10		There is not guiding behavior	X26
	Signage	Signage misplaced	X11		Personnel have their backs to the direction of oncoming traffic	X27
		Dumped signage	X12	Traffic Guides Cone markers	Cone markers are not placed properly	X28
		Insufficient length	X13		Space between cone markers is too large	X29
Buffer area	Length	Not set	X14		Poorly shape of cone markers	X30
Downstream transition area	Settings	Not set	X15	Cone markers	Marker patrol is not timely	X31
Termination area	Settings	Insufficient length	X16			

Similarly, the construction risk factors mainly include personnel equipment, construction equipment and materials. The Risk of Personnel Equipment include whether they wear the correct clothing adopt to the type of maintenance work. Construction Equipment and Materials Risk include whether the construction personnel are operating the equipment correctly and whether the construction materials are safely stacked. The risk factors are represented by $Y_j, j = 1,2,3...$, as shown in the Table 2.

Table 2. Construction Risk Factors

Type	risk factors		Code	Type	risk factors		Code
Construction personnel	Safety shoes	Not wearing safety shoes	Y1	Construction vehicles	Vehicle movement	Dangerous access to work area	Y8
	Safety helmets	Without safety helmet	Y2	Construction Management	Construction materials and equipment	Gas equipment lying down	Y9
	Safety ropes	Not wearing safety harness	Y3			Messy equipment pipework	Y10
	Reflective clothing	Not wearing reflective clothing	Y4			Violent loading and unloading	Y11
	Location	Standing in dangerous positions	Y5			Material poking out of the control area	Y12
Construction vehicles	Vehicle use	Carrying people	Y6		Work	Illegal work	Y13
	Vehicle movement	Unregulated driving	Y7				

3 Risk evaluation model

3.1 Risk evaluation model construction

This paper mainly analyzed the factors of deploy and control, construction, and established a risk assessment model including the two aspects and also other risk factors.

(1) Risk values (D_1) calculation of deploy and control

$$D_1 = \frac{m_i}{M}\sum_{i=0}^{m} d_{1i} \tag{1}$$

Where d_{1i} is the risk value of risk factor i of deploy and control; m is the number of risk factors; m_i is the occurrence number of risk factor i; M is the total occurrence number of risk factors.

(2) Risk values (D_2) calculation of construction

$$D_2 = \frac{n_j}{M}\sum_{j=0}^{n} d_{2j} \tag{2}$$

Where d_{2i} is the risk value of risk factor j of construction; n is the number of risk factors; n_j is the occurrence number of risk factor j; N is the total occurrence number of risk factors.

(3) Risk value setting for other risk factors. In the maintenance workzone, in addition to the deploy and control, construction, the performance of maintenance equipment, and the proficiency of workers are other safety risk factors. In summary, a risk evaluation model (D)for freeway workzone was developed, namely:

$$D = \alpha \cdot D_1 + \beta \cdot D_2 + \gamma \cdot D_3 \tag{3}$$

α, β and γ are the proportions of risk values for the deploy and control, construction and other factors respectively, $\alpha + \beta + \gamma = 1$. The risk value of the maintenance workzone was calculated according to Formula (3).

3.2 Method analysis

The research framework of the paper is shown in figure 2. Through field research and literature review, the paper identified the risk factors in freeway maintenance workzone and collected relevant data, improved LEC method according to the characteristics of maintenance operations, and then established a risk assessment model. The Apriori method was also used to mine and process the data.

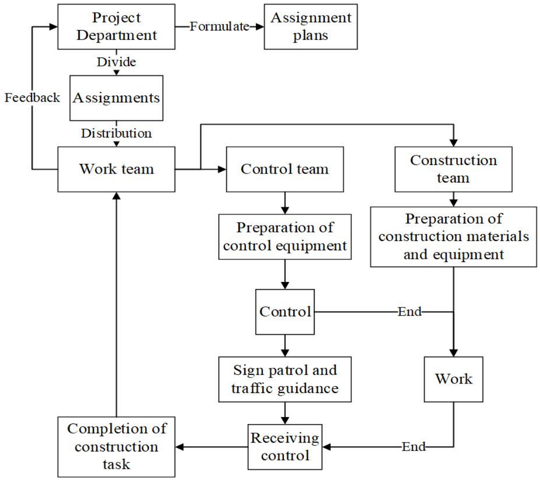

Fig. 1. The operation flow of freeway maintenance workzone

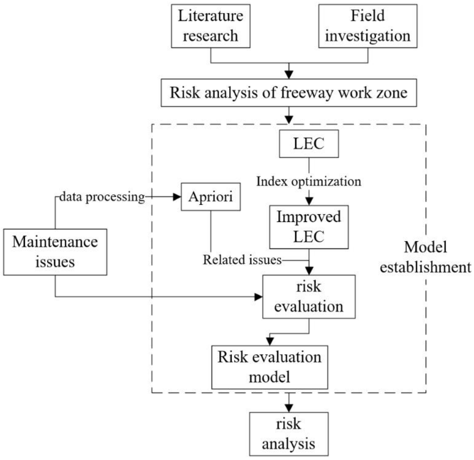

Fig. 2. Research framework

The LEC method can provide a semi-quantitative safety evaluation on the hazards in a potentially dangerous working environment and gain risk values for various factors, visually display the risk level of each risk factor, which is convenient for managers to find the key risk factors. The risk levels are classified as shown in Table 3. LEC uses the product of indictor values of three factors to evaluate the risk, namely: L - the likelihood of an accident occurring; E - the frequency of human exposure to the hazardous environment; C - the consequences of damage that would result if an accident occurred.

Then the hazard D:

$$D = L \times E \times C \ . \tag{4}$$

Table 3. Classification of Security Risk Levels

Risk level	Type of risk	Level of danger	Value at risk (D)
I	Significant risks	Extremely dangerous	D≥320
II	Greater risk	Significant hazards	160≤D＜320
III	General risks	Major hazards	70≤D＜160
IV	Low risk	General hazards	D≤70

The Apriori algorithm was used to explore risk factors with strong correlations in maintenance operations, analyzed the causes of the associated risk factors. To further deduce implied rules, correlations or causal relationships. The calculation process involves searching for frequent itemset and then mining association rules from them.

3.3 Method improvement

The factors evaluation of traditional LEC is basically evaluated by experts in relevant fields, with more subjective factors. Based on the field data collection and question analysis of workzone, the paper optimized the indicators of E and C to make the indicator grading visually reflect the characteristics of the problems in the maintenance workzone.

(1) Optimization of risk factor evaluation indicators for deploy and control is shown in Table 4.

Table 4. Risk Factors Evaluation Table of Deploy and Control

L		E		C	
Score	Possibility of occurrence	Score	Occurrence	Score	Possible outcomes of the problem
10	Totally predictable	10	100%	100	There have been casualties
6	Possible	6	45%≤P＜100%	40	Vehicle plowed into work area
3	Possible but infrequent	3	30%≤P＜45%	15	Vehicle collision care facilities
1	Very unlikely	2	15%≤P＜30%	7	Vehicles queuing at low speed
0.5	Unlikely	1	5%≤P＜15%	3	Vehicles start to queue
0.2	Impossible	0.5	P＜5%	1	Vehicle acceleration, deceleration or lane change

(2) Optimization of risk factor evaluation indicators for construction is shown in Table 5.

Table 5. Risk Factors Evaluation Table of Construction

L		E		C	
Score	Possibility of occurrence	Score	Occurrence	Score	Possible outcomes of the problem

10	Would be totally predictable	10	100%	100	More than 6 deaths
6	Occasionally	6	30%≤P＜100%	40	3-5 deaths
3	Possibly	4	20%≤P＜30%	15	1-2 deaths
2	Possible but not often	3	15%≤P＜20%	7	Serious
1	Very unlikely	2	10%≤P＜15%	5	Seriously injured
0.5	Unlikely	1	5%≤P＜10%	3	Minor injuries
0.2	Unlikely	0.5	P＜5%	1	Collision, bump, crush, etc.

(3) Correlation Influence of risk factors.

According to the correlation analysis on the risk factors of deploy and control, construction process, the occurrence frequency of risk factors with strong correlation rules maintains a certain impact relationship. For example, if the score for risk factor A is 3 and B is 2, but A-B has a strong association rule, then, when A occurs, B has a high probability of occurrence with score bigger than 2.

4 A case study based on the risk evaluation model

4.1 Data sources and classification

The data was derived from a provincial freeway maintenance project. During the project, made statistics on the rectification notice issued by the maintenance unit after the safety inspection on each construction team. Then obtained the statistical data of each team for a sample of 33 days during the project.

The risk factors of deploy and control were divided into six categories according to the sections and control situation: warning zone, upstream transition zone, buffer zone, downstream transition zone, termination zone, and control deploy and control; The construction risk factors were divided into three categories according to the construction content: construction personnel, construction vehicles, and construction management. The cone mark issue was quite serious, which was listed separately.

4.2 Data processing

4.2.1 Data processing for deploy and control problems

Set deploy and control risk factors as database D_1. In the initial setting, in order to obtain more rules, the values of minimum support degree and minimum confidence level are set on the small side, after which targeted screening and analysis will be carried out. Based on the characteristics of this problem, a minimum support degree of 20% and a confidence level of 70% were set.

(1) Find the maximum frequent itemset. Based on databaseD_1, the pruning strategy was used to cut out "no specialized staff", which produced frequent 2-item set (Table 6) based on minimum support of 20%.

Table 6. Frequent 2-item Sets of Deploy and Control Issues

itemset	Code	Support
{Insufficient length of upstream transition area, no traffic guide for control}	{X8，X24}	21%
{No signage in upstream transition area, no traffic guide for control}	{X9，X24}	21%

(2) Mine association rules from frequent itemset. The association rules for the maximum frequent itemset {X8, X24}, {X9, X24} are calculated as shown in Table 7.

Table 7. Correlating Rules of Deploy and Control Issues

Association rules	Code	Confidence	lift
{Insufficient length of the upstream transition zone} → {No traffic guide for control}	{X8}→{X24}	70%	1.46
{No traffic warden} → {Insufficient length of the upstream transition zone}	{X24}→{X8}	43.75%	1.46
{Lack of signage in the upstream transition zone} → {No traffic guide on deploy and control}	{X9}→{X24}	87.5%	1.82
{No traffic guide} → {No signage in upstream transition zone}	{X24}→{X9}	43.75%	1.82

Get: {X8}-{X24}, {X9}-{X24} are strong correlation rules, and the lift levels all are greater than 1, and there is a positive correlation between them.

4.2.2 Data processing for construction problems

Set construction risk factors database D_2, minimum support degree of 10% and confidence level of 70%.

(1) Find the maximum set of frequent items. As above, the frequent 2-item sets (Table 8) were obtained.

Table 8. Frequent 2-item Sets of Construction Problems

Item set	Code	Support
{Workers not wearing safety helmets, workers not wearing reflective clothing}	{Y2，Y4}	12.5%
{Gas equipment lying down, equipment piping in disorder}	{Y9，Y10}	12.5%

(2) Mine association rules from frequent item sets. The association rules for the maximum frequent item sets {Y2, Y4}, {Y9, Y10} were calculated as shown in Table 9

Table 9. Association Rules for Conservation Construction Problems

Associated Rules	Code	Confidence	lift
{Construction worker not wearing helmet} → {not wearing reflective clothing}	{Y2}→{Y4}	45%	2.65

{Worker not wearing reflective clothing} → {Worker not wearing helmet}	{Y4}→{Y2}	76%	2.62
{Gas equipment lying down} → {Equipment pipework in disorder}	{Y9}→{Y10}	52%	3.06
{Equipment pipework in disorder} → {Gas equipment lying down}	{Y10}→{Y9}	76%	3.04

The result shows: {Y4}-{Y2}, {Y10}-{Y9} are strong correlation rules and the lift level are all greater than 1. Namely, there are positive correlations between them.

4.2.3 Analysis on correlation problems

The causes of problems with strong association rules are analyzed as shown in Table 10. Maintenance managers can take appropriate measures to avoid problems based on the causes. For example, by setting correct position of starting stakes can avoid inadequate length of upstream transition area.

Table 10. Analysis on the Causes of Correlation Problems

Type		Reason for occurrence
Conservation operations deployment issues	Inadequate length of upstream transition area	Incorrect position of starting stakes. Excessive haste in pre-positioning. Inaccurate lay-out plan.
	Missing signage at the upstream transition area	Inadequate signage in the plant area. No placards loaded by the deploy and control staff.
	No traffic guide	Involvement of traffic guides in construction. Traffic guide AWOL.
Conservation operations construction issues	No reflective clothing	Not provided by the squad. Reflective clothing was damaged.
	No safety helmet	Shift not provided. Employee information not reported.
	Equipment piping in disarray	Equipment loading and unloading is not standardized.
	Gas equipment lying down	Convenience of construction personnel. Stability of road surface equipment lying down.

4.3 Calculation of risk value

According to the formula (4), the risk evaluation was carried out for deploy and control, construction. Among the risk factors of deploy and control: the risk value of Insufficient Length of Upstream Transition Zone, No Traffic Guide, Traffic Guide Back to the Direction of Incoming Traffic, Poor Cone Marker Line Shape and Untimely Inspection Marker are 135, 108, 100, 90, 90 respectively, which risk level is III and is general risk. The risk value of excessive cone marker spacing is 720, the safety risk level is I, which is a significant risk. All the other control risk factors are low risk. In the construction, the risk value of Workers Not Wearing Safety Ropes is 90, which is a general risk; all other construction risk factors are low risk. In summary, in maintenance operation, we need to strengthen the inspection of cone markers to ensure that the placement of cone markers is in line with the deploy and control plan; Safety officers need to strictly review whether the traffic guides are on duty and guiding the traffic flow, and whether the maintenance equipment of special operators are fully worn.

4.4 Risk assessment of maintenance operation area

(1) Risk value calculation. The calculated risk value and occurrence times of each risk factor are substituted into equation (1) and equation (2), obtain the following values: $D_1 = 96,\ D_2 = 22$.

During the freeway maintenance operation, the newness of maintenance equipment, the quality of maintenance equipment, the proficiency of workers, etc., the conditions of vehicle application, the type of construction materials, etc. are other safety factors in the maintenance operation area. Through Table 1 and Table 2, conducted risk evaluation on the above risk factors, the result shows that the risk value of other risk factors is between 15 and 45, so $\{15 \leq D_1 < 45\}$.

(2) Calculation of weights. A kind of independence weight method was used to determine the values of α, β and γ. The independence weighting method is an objective weighting method that uses the strength of covariance between indicators to determine the weights.

The relevant practitioners' evaluation of the importance of deploy control, construction and other risk factors were collected. By distributing questionnaires to the project works manager, each site safety officer, construction manager and construction personnel, the evaluation of risk importance of relevant practitioners on the above issues are obtained. According to the risk importance evaluation table, the values of α, β and γ were calculated using SPSSAU and the results are shown in Table 11.

Table 11. Independence Weighting Method Calculation Results

Item	Correlation coefficient R	Inverse of the complex correlation coefficient 1/R	Weighting
Risk of control factors	0.636	1.572	36.80%
Risk of construction factors	0.694	1.441	33.74%
Risk of other factors	0.795	1.258	29.46%

Therefore $\alpha = 0.368$, $\beta = 0.3374$ and $\gamma = 0.2946$

(3) Total risk value calculation. Substituting the value of α, β, γ into equation (3) gained $D = \{47 \leq D = \alpha \times D_1 + \beta \times D_2 + \gamma \times D_3 < 56\}$ .Therefore, the risk value of the maintenance operation is between 47-56, the risk level is IV, the risk type belongs to low risk, the degree of danger is general risk. Except for the potential risk brought by the problem of Excessive Spacing of Cone Markers, on the whole, the safety degree of this maintenance operation area is higher.

4.5 Model validation

The feasibility and reliability of the risk analysis model were verified by analyzing the accidents that occurred in the maintenance area of a certain freeway. According to the survey and statistical data, during the maintenance operation, three accidents occurred: maintenance vehicle backing crushing maintenance personnel, construction equipment injuring maintenance personnel, foreign vehicles colliding with the work area and traffic guides, respectively denoted by S1, S2 and S3. The direct problems that led to the accident and the maintenance operations on the day of the accident were analyzed from the perspective of the maintenance operation area, as shown in Table 12.

Table 12. Incident Problems

Accidents	Direct questions	Same day conservation operations problems	Other problems
S1	{Y1}, {Y5}	{X2}, {X8}, {X9}, {X24}	Drivers not paying attention to traffic, etc.
S2	{Y13}	{X21}, {X28}	Complex geology of the construction road
S3	{X25}, {X26}, {X27}, {X28}	{X2}	Quality of cone markers

According to Table 3, questions {X2}, {X9}, {Y1}, {Y5} in S1 have risk values less than 70, which are general hazards. {X8}, {X24} have risk values between 70 and 160, which are significant hazards; Questions {X21}, {X28}, {Y13} in S2 have risk values less than 70, which are general hazards; {X25}, {X26}, {X28} have risk values of less than 70, which are general hazard, and {X27} has a risk value between 70 and 160, which is a major hazard. In addition, according to the model calculation results, the overall risk values were $37 \leq D_{S1} < 45$, $35 \leq D_{S2} < 44$ and $52 \leq D_{S3} < 8$ when S1, S2 and S3 occurred. The risk level was general hazard when S1 and S2 occurred, with a low risk level, and the injuries sustained in the accident were minor, which was in line with the actual situation. The risk level of the maintenance workzone was between general hazard and major hazard when S3 occurred, which was consistent with the higher risk of the maintenance workzone at the time of the transfer.

5 Discussion and conclusion

The paper used Apriori algorithm to pre-mine safety data with strongly interrelated problems, which can be used to guide the risk evaluation of each maintenance problem, and improve the authenticity of the evaluation results. Based on the improved LEC method, the paper established a risk assessment model, and conducted overall risk assessment from two aspects: deploy and control, construction. The method introduced in this paper can be applied to all types of freeway maintenance projects and provide scientific methods for managers to evaluate subsequent maintenance operations. The study can provide a new perspective to the current methods for the safety evaluation on freeway maintenance research operations, which makes the results closer to the actual situation and reduces the influence of subjective factors.

References

1. Liu Min, Lei Han. Analysis and countermeasures of factors affecting the safe operation of freeway maintenance construction[J]. Yunnan Hydropower,2022,38(03):108-110.
2. Yang W.A., Xie Y.Z.. SEM-based analysis of key safety risks in freeway maintenance operation areas[J]. Engineering Economics,2021,31(12):31-35. doi:10.19298/j.cnki.1672-2442.202112031.
3. Moradpour S, Long S. Using combined multi-criteria decision-making and data mining methods for workzone safety: A case analysis[J]. Case Studies on Transport Policy, 2019, 7(2): 178-184.
4. Chukwuma Nnaji,John Gambatese,Hyun Woo Lee,Fan Zhang.Improving construction workzone safety using technology:A systematic review of applicable technologies[J]. Journal of Traffic and Transportation Engineering(English Edition),2020,7(01):61-75.
5. Lou Yuexin,Lu Jian. A study of safety-oriented evaluation model for road maintenance program[J]. Journal of Transportation Information and Safety,2018,36(02):24-32.
6. Chen E, Tarko A P. Modeling safety of freeway workzones with random parameters and random effects models[J]. Analytic Methods in Accident Research, 2014, 1: 86-95.
7. Yang Yang,Yuan Zhenzhou,Wang Yinhai,Wang Wencheng,Sun Dongye. Freeway crash risk identification based on a new improved method of WOMDI-Apriori algorithm[J]. Traffic Engineering,2021,21(06):1-10+16.DOI:10.13986/j.cnki.jote.2021.06.001.
8. Zhuoran Zhang, Burcu Akinci, Sean Qian,Inferring the causal effect of workzones on crashes: Methodology and a case study,Analytic Methods in Accident Research,Volume 33,2022,100203,ISSN 2213-6657.
9. Junyu Hang, Xuedong Yan, Xiaomeng Li, Ke Duan,In-vehicle warnings for workzone and related rear-end collisions: A driving simulator experiment,Accident Analysis and Prevention,Volume 174,2022,106768,ISSN 0001-4575
10. Francesca La Torre, Lorenzo Domenichini, Alessandro Nocentini,Effects of stationary workzones on motorway crashes,Safety Science,Volume 92,2017,Pages 148-159,ISSN 0925-7535.