

Research Article

Road Assessment Model and Pilot Application in China

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Risk assessment of roads is an effective approach for road agencies to determine safety improvement investments. It can increase the cost-effective returns in crash and injury reductions. To get a powerful Chinese risk assessment model, Research Institute of Highway (RIOH) is developing China Road Assessment Programme (ChinaRAP) model to show the traffic crashes in China in partnership with International Road Assessment Programme (iRAP). The ChinaRAP model is based upon RIOH's achievements and iRAP models. This paper documents part of ChinaRAP's research work, mainly including the RIOH model and its pilot application in a province in China.

1. Introduction

With the fast urbanization and motorization in China, the highway network is expanding quickly. By the end of 2011, the total length of operating technical highways is more than 35.37 million km including 85,000 km expressways [1]. However, China is also facing huge traffic safety challenge as a result of blasted traffic volume and complex traffic compositions. In 2012, about 60,000 persons lost their lives in traffic accidents in China [2]. The accidents have also caused huge economic loss.

Since traffic safety issue is a world disaster, many research and actual countermeasures have been performed to improve traffic safety conditions. In current traffic safety theory system, traffic safety management and traffic safety risk assessment [3] are two main systematic tools to direct actual traffic safety projects. Among these two tools, traffic safety risk assessment has been shown to be an effective method to evaluate the highway network safety level. It also makes economic plan based on benefit to cost (B/C) analysis, which is the ratio of the estimated safety benefit to the cost of actual countermeasures. Traffic safety risk assessment is an integration of historical effective achievements including accident prediction model, countermeasure effect appraisal, and economy analysis. Many methods have been used to predict the relationship between accidents and roadway

geometric characters as well as traffic related explanatory factors, such as multiple linear regression, Poisson regression and negative binomial regression, the zero-inflated Poisson model, and the generalized estimating equations [4–9]. To make decisions on appropriate treatments selection, know the estimated effects of such countermeasures and support the address of crash problem based on the expected crash reduction. Many safety countermeasure effect appraisals are performed including empirical and statistic (such as EB model) methods and the results eventually are expressed as crash reduction factors [10–13]. The main objective of economy analysis is to express the crash loss in economic index which can match the cost and benefit very well [14].

iRAP model has been undertaken in many countries all over the world as a sophisticated risk assessment method. The iRAP method includes data collection, survey, coding, assessment, and economic appraisal phrases [4]. The building of the “China Road Assessment Program (ChinaRAP)” project was undertaken in partnership between the RIOH and iRAP, and the objective was to develop road infrastructure risk assessment models that draw on iRAP and RIOH knowledge for application in China. During the pilot project, both RIOH and iRAP risk assessment models were used, and this paper introduces the RIOH method in the research. This paper shows the basic framework of RIOH model, its pilot application procedure, and the assessment results.

TABLE 1: RIOH standard of safety levels.

Level	Standard scope (injury accidents per km)
5	0.00 to 0.24
4	0.24 to 0.35
3	0.35 to 0.51
2	0.51 to 0.85
1	>0.85

2. RIOH Risk Assessment Model

The RIOH risk assessment model is an integration of research achievements by RIOH, including safety audit theory, accident predication model, countermeasure effect appraisal, and accident loss economy analysis.

RIOH risk scores are indicated by the injury accident rate calculated by basic accident rate and the influence of actual traffic safety factors. The values of the influence of actual traffic safety factors are generated from statistical models and some before-and-after analysis results. To express the safety condition, 5 levels are used in which 1 is the worst and 5 is the best, as shown in Table 1. In the safety level map, green is the lowest risk and black is the highest risk. Based on the analysis of risk scores, the economic analysis provides some estimation of the benefit of countermeasures and B/C rate.

In RIOH model, highways are separated into general segments, village segments, and intersections. To show the framework of RIOH model, an example for all accidents calculation of general segments is illustrated below. It includes a basic safety condition (showed in Table 2 for general segments) and safety index of actual factors:

$$P_{cq} = \text{expo} \times BP_{cq} \times P_{cqr} = \text{expo} \times BP_{cq} \times P_{cq1} \cdots \times P_{cqm}, \quad (1)$$

where P_{cq} is all accidents rate of general segment, $\text{expo} = (365 \times zr \times y)/1000000$, zr is traffic volume, y is year, BP_{cq} is basic accident rate of P_{cq} , P_{cqr} is actual accident rate of P_{cq} , and P_{cqm} is the actual m th factor of P_{cq} , such as for lighting. For total accidents of general segments, $BP_{cq} = 0.69$.

The basic road condition of general segments is shown in Table 2.

3. Model Application on Road Network

3.1. Road Network. In total, 374.1km of 9 roads in China was surveyed and fully assessed for the pilot project. Table 3 summarizes the length of class of each road. For the purpose of this study, the informal name of “class 2a” is given to roads that are typically class 2 but have been upgraded to have two lanes of traffic in each direction and do not have median separation.

3.2. Road Survey Data. To match the basic data requirement of assessment, data collection and survey work was performed on the road network. Data collection included traffic volume, typical countermeasure costs, and economics and demographics data. Road network was surveyed using RIOH’s existing survey method, including two video cameras,

TABLE 2: Basic road condition of general segments.

Attributes	Description
Design speed	Low (≤ 30 km/h)
Segment character	Not bridge or tunnel
Surface character	Pitch surface
Directing signs	No
Warning signs	No
Lighting	No
Medial marking	No
Edge marking	No
Pedestrian crossing line	No
Linked to village	No
Turing angle	Straight
Gradient	Plain
Bicycle percentage	Average (3%)
Bus percentage	Average (10%)
Motorcycle percentage	Average (7%)
Driveway density	No

GPS, and recording of observations by road engineers. For using the survey videos and GPS, road attributes on building ChinaRAP network were coded at 0.1 km intervals. A summary of the road attributes by road class is shown in Table 4.

4. Pilot Application Procedure and Results

Based on the coding data and some other basic data such as countermeasure cost, the risk assessment is performed. The actual application procedure includes 3 stages: model assessment to produce risk maps, investment plan analysis to order the countermeasures by B/C rate, and the predictive effect analysis to direct the location where we will get best accident reduction.

4.1. Model Assessment Results. Model assessment results include two parts; one is total assessment results and the second is results for every segment to produce the risk map. Table 5 shows the predicted accident density on pilot road network. It is noted that although 17 attributes were used to set the baseline accident rate for general segments (as shown in Table 4) and a total of 18 attributes were used for all segment types (common, village, and intersection), for the purposes of this pilot application, a total of ten attributes were used.

The predictive accident density of all users is showed in Table 6, whose total predictive injury accident numbers are 226.6 injury accidents. The actual injury accident number with accurate location in the network is about 153.4 per year (accident density is 0.41 per km). However, as there are only 63% accidents which have detailed location information, the total accident number is actually about 242.3 per year, which shows that RIOH results underestimate the level of risk on the roads.

Table 6 shows the predicted accident densities according to the thresholds discussed earlier (as shown in Table 12).

Figure 1 shows the accident densities in map form.

TABLE 3: Network surveyed.

Road name	Class 1 (km)	Class 2a (km)	Class 2 (km)	Class 3 (km)	Urban (km)	Total (km)
Road 2	36.3	5.2	4.7			46.2
Road 9			31.1			31.1
Road 3	11.6		32.1			43.7
Road 4			44.3			44.3
Road 1		1.0	58.0			59.0
Road 5			6.0		13.6	19.6
Road 6	7.2	14.2	31.4			52.8
Road 7			27.8			27.8
Road 8				49.6		49.6
Total	55.1	20.4	235.4	49.6	13.6	374.1



FIGURE 1: RIOH all occupants of accident density map.



FIGURE 2: RIOH predicted accident rate decreasing map.

4.2. *Investment Plan.* Economy analysis is based on the calculation of life cost and countermeasure cost together with the difference of risk score before-and-after countermeasures are implemented, which can measure economic invest and accident loss in the same way. To match the model skeleton and express it simply, the safety effect of countermeasures was calculated individually, and no relation is thought for complex countermeasures. For the purposes of this pilot, six kinds of countermeasures were appraised, as shown in Table 7.

Table 8 shows a summary of the investment plan results, in which center marking, pedestrian crosswalk, and roadside marking are with the highest benefit cost ratios. Table 8 indicates that an investment of approximately RMB 130,246,350 could prevent 86.34 serious accidents per year in the 10-year future. Over 10 years, more than RMB 130,246,350 in injury crash costs could be saved, leading to a benefit cost ratio of 15.96 : 1.

4.3. *Predictive Results.* It is important to pinpoint the locations where we can get the biggest accident reduction effects in actual improvement projects. Figure 2 map shows the locations where injury accidents rate (per km per year for all users) could be prevented over the next 10 years if the investment plan is implemented. Levels 1 and 2 sections of road are where the most injury accidents could be prevented



FIGURE 3: RIOH all occupants of risk rating map with countermeasures performance.

(Table 9). Levels 3, 4, and 5 sections are where the fewest could be prevented.

The percentage summary of future injury accidents decreasing levels if countermeasures are performed is shown in Table 10.

The Figure 3 map below shows the predicted risk rating map with countermeasures performance under the same standard in Table 11.

The predictive safety effects for all users if countermeasures are performed without changing traffic factors are

TABLE 4: Key data and road attributes.

Attribute	Category	Class				
		1	2a	2	3	Urban
Length (km)		55.1	20.4	235.4	49.6	13.6
AADT		11305	9606	8013	3855	4006
Motorcycle flow (% of AADT)	21%–40%	0%	0%	0%	100%	0%
	11%–20%	87%	40%	52%	0%	0%
	6%–10%	13%	60%	36%	0%	0%
	1%–5%	0%	0%	13%	0%	100%
Bicycle flow	Low	100%	100%	100%	100%	100%
	High	0%	0%	7%	2%	0%
Pedestrian flow (along)	Medium	48%	19%	43%	24%	63%
	Low	49%	77%	46%	74%	37%
	None	3%	4%	3%	0%	1%
Delineation	Poor	96%	69%	60%	59%	84%
	Adequate	4%	31%	40%	41%	16%
Intersection quality	Poor	53%	66%	78%	95%	67%
	Good	47%	34%	22%	5%	33%
Lane width	Medium	13%	47%	15%	0%	0%
	Wide	87%	53%	85%	100%	100%
Curvature	Sharp curve	0%	0%	1%	4%	0%
	Moderate curvature	5%	2%	14%	20%	6%
	Straight or gently curving	95%	98%	86%	76%	94%
Overtaking demand	High	0%	0%	83%	0%	0%
	Medium	0%	0%	0%	99%	0%
	Low	0%	100%	14%	1%	84%
	None	100%	0%	3%	0%	16%
Side friction	High	0%	0%	0%	1%	1%
	Medium	2%	3%	2%	0%	1%
	Low	98%	97%	98%	99%	99%
Pavement condition	Poor	0%	0%	0%	53%	0%
	Medium	4%	1%	5%	29%	0%
	Good	96%	99%	95%	18%	100%
Roadside severity (right)	Cliff	0%	0%	1%	0%	0%
	Motorcyclist friendly barrier	1%	0%	0%	0%	1%
	Distance to object >10 m	0%	0%	1%	0%	0%
	Distance to object 5–10 m	0%	0%	0%	0%	29%
	Distance to object 0–5 m	57%	74%	73%	20%	53%
	Steep fill embankment slopes	0%	0%	4%	17%	0%
	Deep drainage ditches	38%	24%	18%	60%	7%
	Cut	2%	0%	1%	2%	8%
Safety barrier	1%	2%	3%	1%	1%	
Pedestrian crossing quality	Poor	62%	39%	39%	100%	36%
	Adequate	38%	61%	61%	0%	64%
Speed	80 km/h	60%	44%	29%	0%	0%
	70 km/h	3%	53%	32%	98%	90%
	60 km/h	37%	2%	40%	2%	10%

TABLE 5: Accident density (injury accident per km per year).

Road number	General segments	Village segments	Intersection	All
Road 1	0.67	0.72	0.14	0.51
Road 2	1.39	1.81	0.07	1.09
Road 3	0.84	0.39	0.03	0.42
Road 4	0.52	0.61	0.03	0.39
Road 5	0.35	0.14	0.01	0.16
Road 6	0.48	0.47	0.03	0.33
Road 7	0.89	0.63	0.03	0.52
Road 8	0.54	0.51	0.11	0.39
Road 9	0.00	0.64	0.05	0.23

TABLE 6: Safety risk level summary results.

Level	Percentage (%)								
	Road 1	Road 2	Road 3	Road 4	Road 5	Road 6	Road 7	Road 8	Road 9
5	10.46	6.54	4.94	5.52	34.90	22.97	24.91	7.68	3.26
4	2.57	0.00	0.00	0.00	27.60	25.15	0.00	3.84	0.00
3	12.35	0.00	49.18	43.68	37.00	16.00	13.00	68.69	0.00
2	65.00	4.58	14.12	49.00	0.00	36.00	34.00	17.17	95.44
1	10.00	89.00	32.00	2.00	0.00	0.00	28.00	3.00	1.00

TABLE 7: Basic condition of countermeasures.

Countermeasures	Unit	Cost (Yuan)	Life cycle
Center marking	Per linear km	7500	2
Roadside marking	Per linear km	6000	2
Angle adjustment	Location	200000	10
Lighting	Per linear km	660000	10
Pedestrian crosswalk	Location	960	2
Roadside barriers	Per linear km	400000	10

TABLE 8: Investment plan summary.

Countermeasures	Length (km)	Accident number decreased per year	Accident benefit of 10 years (Yuan)	Cost per year per km	Total cost (Yuan)	B/C
Center marking	185.3	33.32	802138853.79	37500	6948750	115.44
Roadside marking	234.4	13.43	323290641.76	30000	7032000	45.97
Angle adjustment	33.6	17.36	417883207.71	200000	67200000	6.22
Lighting	53.2	12.10	291371924.31	660000	35112000	8.30
Pedestrian crosswalk	5.7	0.94	22611161.78	4800	273600	82.64
Roadside barriers	34.2	9.19	221229629.94	800000	13680000	16.17
Total		86.34	2078525419.30	1792300	130246350	15.96

TABLE 9: Standard of injury accidents decreasing levels.

Road user	Accident decreasing level	Standard scope (injury accidents decrease per km)
All	5	0.000–0.048
	4	0.048–0.201
	3	0.201–0.435
	2	0.435–0.896
	1	>0.896

shown in Table 12, which indicates that there will be more levels 4 and 5 roads. In these 9 roads, road 2 will get the biggest results to decrease the level 1 segments, and road 1, road 2, and road 9 will get evident results to reduce low level segments.

5. Conclusions and Prospects

China is facing huge traffic safety problems with the increase of roadway length, traffic volume, and complex traffic composition. As a systematic method to determine road safety

TABLE 10: Summary of injury accidents decreasing levels in network.

Decreasing level	Percentage (%)								
	Road 1	Road 2	Road 3	Road 4	Road 5	Road 6	Road 7	Road 8	Road 9
5	9.43	3.05	4.94	15.40	17.71	29.50	23.47	7.68	7.49
4	21.61	3.27	44.71	40.46	41.67	19.01	19.86	29.29	28.99
3	30.19	9.37	16.24	21.84	14.00	26.00	15.00	15.96	49.19
2	33.00	42.48	22.82	22.00	27.00	15.00	24.00	47.07	14.33
1	5.00	42.00	11.00	1.00	0.00	10.00	18.00	0.00	0.00

TABLE 11: Safety risk level summary results for all users with countermeasures performance.

Decreasing level	Percentage (%)								
	Road 1	Road 2	Road 3	Road 4	Road 5	Road 6	Road 7	Road 8	Road 9
5	35.33	29.85	18.82	27.82	83.33	47.13	61.73	81.21	16.61
4	27.62	10.68	62.59	25.52	16.67	24.75	0.36	11.92	45.93
3	15.95	3.27	4.24	24.37	0.00	21.00	9.00	4.85	31.92
2	18.00	14.60	10.35	22.00	0.00	7.00	27.00	1.82	4.89
1	3.00	42.00	4.00	0.00	0.00	0.00	2.00	0.00	1.00

TABLE 12: Safety risk level difference results for all users with countermeasures performance.

Decreasing level	Percentage (%)								
	Road 1	Road 2	Road 3	Road 4	Road 5	Road 6	Road 7	Road 8	Road 9
5	24.87	23.31	13.88	22.30	48.44	24.16	36.82	73.54	13.36
4	25.04	10.68	62.59	25.52	-10.94	-0.40	0.36	8.08	45.93
3	3.60	3.27	-44.94	-19.31	-37.50	4.95	-4.69	-63.84	31.92
2	-47.34	10.02	-3.76	-26.67	0.00	-28.71	-6.50	-15.35	-90.55
1	-6.17	-47.28	-27.76	-1.84	0.00	0.00	-25.99	-2.42	-0.65

treatments for the agencies to ensure the most cost-effective returns in crash and injury reductions, traffic safety risk assessment has been researched and used widely all over the world. To match the actual safety conditions in China, RIOH is building ChinaRAP cooperating with iRAP in the pilot projects. Both RIOH model and iRAP model are used to find the model adaption, and this paper shows the RIOH method in the research, including the brief introduction of the model framework, the model procedure, and some initial results.

Under the pilot application, it is considered that total assessment result for whole road network is similar to the actual accident. For the investment plan, center marking, pedestrian crosswalk, and roadside marking are found to have the highest benefit cost ratios, which can reduce the injury accident evidently, such as road 2; about 47.28% level 1 roads will be upgraded to higher safety level roads, especially road 1, road 2, and road 9 which will get evident results to reduce low level segments.

Initially, ChinaRAP can be put into application to produce useful and helpful safety projects in China. However, building ChinaRAP must be a hard and long time work aiming for actual application. For example, limited by the traffic safety research of countermeasure effects, especially before-and-after analysis, it is still difficult to get actual risk scores for some safety factors, and we cannot simply use foreign results without test in Chinese condition. In future works,

the assessment results will be compared directly to actual accident distribution characteristic and then the deeply test and the adjustment of risk scores. Also large amount of traffic safety data accumulation, especially accident data, should be increased in order to direct before-and-after analysis and get more reasonable results.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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