Identifying the Crash Worthiness and Crash Avoidance Factors Based on Road Features

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Abstract. The increased rate of road fatalities ad injured has been a vital issue. Risk assessment of road projects is essential in the pre-construction stages to prevent road crashes from occurring in the operational stage. Identifying the contributing factors of road safety is essential to propose countermeasures and control the issue of the increase in road fatalities. These factors are categorized according to the transportation system's main elements: road users, infrastructure, and vehicles. They are also categorized according to the likelihood of crashes reflecting the crashworthiness factors and the severity of crashes reflecting the crash-occurrence factors. This paper aims to identify the factors related to road features affecting the likelihood and severity of crashes in a selected road section in Iraq. The selected road section is a portion of the main transport corridor, expressway 1/R9, designed to connect major cities and is used by significant traffic volume, leading to increased crash fatalities. The selected section connects Al-Bushajal with Al-Malahima village in Ramadi City. The selected tool is the International Road Assessment Program (iRAP), a valid risk assessment at road networks. The assessment output is in terms of star rating and star rating score. A higher star rating means safer road conditions, while a higher star rating score means more dangerous road conditions. The assessment results show high vehicle risk levels, and two types of crashes are diagnosed as the most common. Road improvements that meet safety standards are proposed, such as resurfacing with adequate overlay, improving delineation, lighting, metal barriers for the median and passenger side, and using shoulder rumble strips. The assessment results after improvements show upgrading the star rating to the recommended minimum (4 and 5) for vehicle occupants.

Keywords: Crash likelihood; crash severity; risk assessment; road rating; iRAP.

1. INTRODUCTION

The risk level of roads has been raised worldwide. Globally, more than 1.2 million individuals are killed, and up to 50 million people are injured yearly in automobile accidents. Deaths account for more than 90% of global mortality in low- and middle-income nations. The long-term effects of traffic accidents, such as the cost of medical care and rehabilitation, and all too frequently, funeral costs and the loss of the family breadwinner, can cause a family to fall into poverty in addition to the immense suffering they cause. Crash survivors and their families often struggle to cope with these long-term effects. Pitifully low resources plague many national health systems and are also under tremendous strain due to road traffic injuries. In the past, many policies put in place to lower traffic-related fatalities and injuries focused on protecting motorists. Nearly half of all yearly fatalities involve walkers, cyclists, motorcyclists, and public transportation passengers [1,2].

Recently, the most successful road projects in the world have incorporated risk assessment in the planning and design stages [3]. The roadway factors are the main factors in this stage, while the factors related to traffic and transportation characteristics are considered mainly in the operating stages [4]. The International Road Assessment Programme (iRAP) is the most valid and recommended tool used to assess the risk level of roads based on road features [7]. The main function of this tool is to rate the risk level of road infrastructures in terms of star rating (SR); one star reflects a high-risk level, while five stars reflect a high-safety level [9]. The outcomes can be categorized into likelihood and severity ratings. The likelihood of crashes interprets the crash-avoidance factors, which are the circumstances that could result in a crash. A greater likelihood rating indicates a lower chance that a crash will occur. The second category is the severity rating, which reflects the crashworthiness level; a lower severity rating indicates that the crash would be more severe and may result in high fatalities and serious injuries.

According to this categorization, road features are also categorized to affect crash avoidance and crashworthiness. These factors are not the same for all crash types and road users. For example, a median significantly reduces the crashworthiness level of head-on crashes for vehicles and motorcyclists, while the lane width and curvature quality affect the crash-avoidance level for the same crash type. The presence of huge objects near the roadside and lack of paved shoulders result in high severity when runoff crash occurs for vehicles, while road conditions may result in this crash type [8,9].

Road rating is highly recommended by the World Bank and the United Nations to achieve the target of upgrading the safety level of road networks in the world; this needs to identify the contributing factors and suggest countermeasures. Despite that, a few attempts have considered road rating tools in Iraq. In addition, the implemented projects of road improvements may be over-costly because the implemented improvements are not related precisely to the contributed factors of the most common crashes on the improved road. For example, removing the closed by edge big trees is more contributed to runoff crashes but is not contributed to rear-end crashes. Furthermore, the contributed factors are categorized according to the crash-avoidance and crashworthiness characteristics. For example, existing big trees close to the edge of pavement (less than 5 m) significantly contribute to increasing the severity of crashes when it occurs. Still, widening contributes more significantly to the likelihood of runoff crashes. Moreover, the contribution factors are different according to road user groups; widening contributes to vehicle occupants and motorcyclist crashes, but pedestrian facilities are more contributed for walking crashes.

This study aims to rate a road section in Iraq, identify the factors related to road features affecting crashes' crash-avoidance and crashworthiness, and categorize them according to the crash types for vehicle occupants.

2. LITERATURE REVIEW

Bellos [14] used the iRAP methodology to carry out a road risk assessment of a 3600 km section of road within the Greek transport network across continental Europe and consider the investment plans designed for road maintenance or rehabilitation. The collection of information from the road was for every 100 meters and its adjacent areas by a vehicle specially equipped to collect information. The collected information was analyzed to evaluate the factors affecting infrastructure risks related to the probability of an accident and the degree of its severity and to give a star rating based on the results of this analysis. Plans to improve road safety and increase the benefit rate over the planned cost was suggested.

Lawson [15] assessed road infrastructure safety of 93km of R7_M2 in Moldova between 2010 and 2015, presented for the existing road and the road after rehabilitation. Through the evaluation, it was recommended to provide 22 km of pavement, increase the number of pedestrian crossings, add safety barriers with a length of 12.3 km, make improvements to both the efficiency of the curves and the quality of the paving surface, and improve the performance and quality of the intersections as they were before the rehabilitation. Before the improvement, the road's safety rating for pedestrians was low (84% received only one or two stars), and it had 87% of the same ratings for motorists. Star ratings have increased since the rebuilding. For bicycles, motorcyclists, pedestrians, and vehicle occupants, the proportion of roads with three stars or higher rose by nearly 30 percentage points. The EuroRAP pre-construction investment proposal demonstrated that, for an extensive set of secure countermeasures, there could be a decrease of around three hundred fatalities or serious injuries during twenty years, with a benefit-cost ratio nearing 4, thereby preventing nearly a quarter of road casualties that would have occurred on the highway had there not been upgrading.

Murozi [16] highlighted the implementation stage and the advantages and disadvantages of applying the iRAP methodology by conducting a review of previous studies that dealt with the issue of applying iRAP in the field of traffic safety in several different countries and finding the gap by comparing it with his research. This methodology included road surveys, degrees of protection, star ratings, and a safe road investment plan. It was found that some of the research studies covered school traffic with iRAP while the rest were focused on highways. All studies produced a star rating and gave a safer investment plan for the road according to the iRAP methodology. Jameel [5] used iRAP methodology to assess two road sections in Iraq (Baghdad-Baqubah) based on the road features. Their results demonstrated the applicability of the selected methodology in assessing the risk level according to road user groups and according to crash types. The risk factors for each crash type and each road user group have been identified and used in proposing countermeasures to upgrade the safety level to the required level. Jameel et al. (2021) have identified the factors according to the likelihood and severity of crashes for head-on and runoff crashes. They found that improving surface conditions, widening, and using shoulder rumble strips can significantly reduce the risk level of runoff crashes, while upgrading the median type significantly reduces the risk of head-on crashes.

Jameel [10] used iRAP tool to analyze the risk factor of Latifiyah expressway section in Iraq and compared the results with the recorded crashes. It is found that runoff crashes are the most common crash diagnosed by the iRAP while the recorded crashes showed that rear-end is also recorded frequently. She recommended improving the surface conditions, using shoulder rumble strips, installing effective lighting, improving the road section's delineations to reduce the risk of runoff crashes, and removing the closed big trees to reduce the risk of runoff crashes.

3. METHODOLOGY

To achieve the aim of the study, the methodology shown in Figure 1 was followed. The details of each step are given below:

3.1 Selection of the Study Area

The chosen road is a section of the Expressway 1- Road No. 9 (R9) highway, which connects Baghdad City and Hit City [11]. The selected section connects Al-Bushajal with Al-Malahima village in Ramadi City, with a length of 10km (from 33.436487, 43.645254 to 33.469727, and 43.548829) as shown in Figure 2. This is a vital section of the highway that connects important areas. It is considered one of the most important roads in the trade exchange between the western borders of Iraq and the rest of its regions. This section of the road was exposed to acts of vandalism in terrorist incidents. For this reason, rehabilitation operations have been initiated under the supervision of the World Bank. It consists of three lanes for each side divided by a physical concrete median in some areas and a metal safety barrier in others. The World Bank has funded the rehabilitation project of the main transport corridor in Iraq to enhance its performance after recuperating from years of war and violence [12].

Selecting the study area

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Data collection: Road attributes and Traffic data

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Quantifying risk level (before and after improvements)

- Investigating and selecting the assessment methodology
- Coding data
- Running the selected methodology

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Improving the safety level

- Proposing countermeasures
- Examining the effectiveness of the proposed countermeasures
- Selecting the final set of proposal

Figure 1: Methodology of the research.

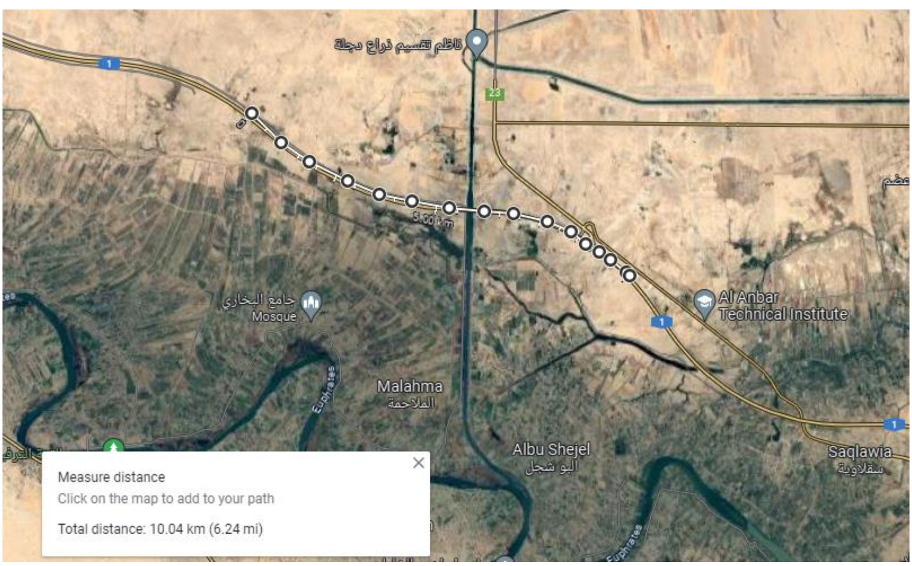

Figure 2: The selected road section.

3.2 Data Collection

The main data needed as input variables for assessing the risk level are classified into road attributes and traffic data. Road attributes are the primary information required for processing the iRAP methodology; it focuses on the road characteristics that influence crash avoidance and crashworthiness. For example, the primary road characteristics that increase the likelihood scores of runoffs and head-on crashes are the lane width, curvature, quality of curves, delineation, road condition, gradients, and skid resistance. The features on the side of the road, such as the paving quality of the shoulders and the presence of objects, are related to the factors that increase the severity score of runoff crashes. Median types and dimensions are needed to assess the severity of head-on crashes (iRAP, 2015). Road attributes were collected from the site observation and plans documented by the Ministry of Construction and Housing / Roads and Bridges Authority. Table 1 shows the recorded road feature for all segments; they are classified into cross-section elements, including roadside characteristics and median types, road conditions, road furniture, and others.

Traffic data includes the average annual daily traffic (AADT) collected from project documents and operation speed collected in the field. The AADT was 9554 vehicles per day along the road section. The traffic flow of motorcyclists, bicyclists, and pedestrians should also be collected; the flow was recorded as zero as there has been no observed flow for these road user groups. The above data are recorded for every 100 m as the iRAP methodology requires.

3.3 Data processing

To process the collected data, they are coded according to the iRAP's methodology codes. For example, when the median type is metal barriers, the code for the median type feature is 1, and when the median type is physical median width 10 to <20m, the code is 4 (iRAP, 2015). Table 1 shows the codes of the recorded road features of the selected road section. These codes are entered in the VIDA, an online software used for risk assessment and star rating analysis tool produced by the iRAP. The outputs are expressed in terms of star rating scores and star ratings categorized into likelihood score (crash-avoidance), severity score (crashworthiness), and overall risk score for all diagnosed crash types. The results are shown in Table 2.

Table 1: Geometric features and codes of the road sections.

Roadside severity-driver-side object		
Distance	**Attribute**	**Codes**
0 to1.5, 1.8, 3.8 to 6.9, 9.4	No object	17
1.6 to 1.7, 3.5 to 3.7, 7 to 7.3, 8.1 to 10	Safety barrier - metal	1
Roadside severity-driver-side distance		
Distance	**Attribute**	**Codes**
0 to 10	>=10m	4
Roadside severity-passenger-side object		
Distance	**Attribute**	**Codes**
Along the road section	No object	17
Roadside severity passenger-side distance		
Distance	**Attribute**	**Codes**
Along the road section	-	-
Median type		
Distance	**Attribute**	**Codes**
0 to 1.5, 1.8to 3.4, 3.8 to 6.9, 7.4 to 8.0	Physical median width 10 to <20m	4
1.6 to 1.7, 3.5 to 3.7, 7 to 7.3, 8.1 to 10	Safety barrier - metal	1
Skid resistance/grip		
Distance	**Attribute**	**Codes**
6.8 to10	Sealed medium	2
0 to 6.8	Sealed adequate	1
Road Condition		
6.8 to10	Medium	2
0 to 6.8	Good	1
Street Lighting		
Distance	**Attribute**	**Codes**
0 to 10	Not Present	1
Others (along the road section)		
Shoulder rumble strips	Not present	1
Paved shoulder - driver-side	Medium (≥ 1.0m to <2.4m)	2
Paved shoulder - passenger-side	Medium (≥ 1.0m to <2.4m)	2
Centreline rumble strips	Not present	1
Number of lanes	three	3
Lane width	Wide (≥ 3.25m)	1
Curvature	Straight or gently curving	1
Quality of curve	Not applicable	3
Grade	≥ 0% to <4%	1
Delineation	Poor	2
Speed management / traffic calming	Not present	1
Roadwork	No road works	1
Sight distance	Adequate	1
Speed limit	120km/h	19

4. RESULTS AND DISCUSSION

The outputs of iRAP running are presented in star rating scores and star rating forms, as shown in Table 2. The results show that two types of crashes are diagnosed with the highest likelihood and severity score, runoff and head-on (due to loss of control) crashes. The likelihood score of runoff and head-on crashes for segments (6.8-10 km) is higher than those for segments (0-6.8 km). The reason is that the road condition and skid resistance for segments (6.8-10 km) is worse than of (0-6.8 km). The poor delineations and lack of street lighting are the main contributing factors to the increase in the likelihood scores at all segments. This highlighted the role of delineation in the risk level of crash-avoidance level. Delineation is considered a cost-effective solution, and it is essential to guide drivers and prevent them from changing lanes, leading to most types of crashes.

The severity score of runoff crashes is equal on the passenger side along the road section because of the same roadside conditions and narrow paved shoulder; no closed hazardous objects exist. On the driver side, some segments have safety metal barriers, which lowered the severity score to 1.2 with a higher safety level. These results highlight the significant role of roadside conditions on crashworthiness, the existence of closed by big objects such as big trees and poles by a distance less than 5m to the pavement edge. The crashes resulting from the diversion of vehicle movement and hitting a hazardous object are more severe than the same crashes without hitting objects. The hitting with roadside objects can be reduced by increasing the distance to the objects, the width of paved shoulders, or the distance to the nearest objects. The overall rating according to runoff crashes is one-star, high-risk level, where there is no safety metal barrier, and between two and three stars, where there are safety barriers; the bad surface condition and skid resistance rating is the reason for lowered safety rating to two where there are safety barriers. Bad surface conditions and high skidding levels increase the likelihood of runoff crashes by increasing the possibility of loss of control that leads to changing movement of vehicles. The severity score of head-on crashes is 0 with a star rating of 5 stars, where there is a median type of safety barrier, but it is 10 with a star rating between 1 and 2, where there is no safety barrier. Installing safety barriers on both sides is one of the important solutions for runoff crashes and head-on crashes.

Table 2: The results of the processing step.

Section (km) / Crash type	Score/star rating category	0.1 To 1.5	1.6 To 1.7	1.8 To 3.4	3.5 To 3.7	3.8 To 6.8	6.9	7 To 7.3	7.4 To 8	8.1 To 10
Vehicle Runoff	Likelihood score	1.5	1.5	1.5	1.5	1.5	2.52	2.52	2.52	2.52
	Severity score/ driver-side	3.5	1.2	3.5	1.2	3.5	3.5	1.2	3.5	1.2
	Severity score/ passenger-side	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
	Star Rating/driver-side	1	3	1	3	1	1	2	1	2
	Star Rating/ passenger-side	1	1	1	1	1	1	1	1	1
Vehicle Head-on LOC	Likelihood	1.44	1.44	1.44	1.44	1.44	2.4192	2.4192	2.4192	2.4192
	Severity	10	0	10	0	10	10	0	10	0
	Star Rating	2	5	2	5	2	1	5	1	5

5. IMPROVEMENT OF THE SAFETY LEVEL

To improve the safety level of the assessed sections, the contributed risk factors of the diagnosed crash types are identified according to previous studies [10,13] to recommend suitable countermeasures. These factors are classified into likelihood factors and severity factors. They reviewed according to the field conditions to select the final set of countermeasures. The suggested countermeasures are shown in Table 3. It can be seen that the proposed countermeasures can reduce the runoff likelihood scores by 20% at segments 1-6.8km and by 53% at segments 6.8 to 10 km. The runoff severity score is reduced by 23% at some segments (where there is already a safety barrier) to 74%, where their new safety barrier will be installed. The overall star rating is upgraded to 4 –stars reflecting a significant safety level improvement.

Regarding the head-on crashes (due to loss of control), the likelihood score is reduced by 17% at segments 1-6.8 km and 50% at segments 6.8-10km, while the severity score is reduced to zero due to installing a safety barrier. The star rating is upgraded to 5 stars reflecting the safest conditions.

6. CONCLUSIONS

The results of this work enhanced the effect of road features on the risk level of road infrastructure. This is consistence with the new visions of road safety studies that focus on improving road attributes to accommodate the drivers' behavior and reduce the rate of their mistakes. Some attributes have roles in improving crash-avoidance conditions and reducing the likelihood of crashes; other attributes affect the crashworthiness severity level. According to this research's results, the likelihood and severity factors are identified according to the crash types. Two types have been diagnosed, runoff crashes and head-on (due to loss of control crashes). Surface conditions, skid resistance, poor delineations, and ineffective lighting are significant factors in runoff and head-on crashes. Resurfacing with clear painted marking, installing shoulder rumble strips, and street lighting would improve the crashworthiness conditions and reduce the likelihood of runoff crashes by 20%-53% and head-on crashes by 17%-50%. The severity of runoff crashes is reduced by 74 % by installing safety barriers and wide paved shoulders. In contrast, the severity of head-on is eliminated when installing a safety barrier at the median. The star rating is upgraded to 4 and 5 for runoff and head-on crashes.

Table 3: Proposed countermeasures.

Crash type	Likelihood/ Severity	Risk factors	Countermeasures	Results after improvements	
				Score	Star rating
Runoff	Likelihood (crash avoidance)	- Road condition - Skid resistance - Lack of street lighting - Poor delineation - Lack of speed management and traffic calming techniques	Resurfacing the pavement with adequate overlay at segments 6.8 to 10 km improves the driving behavior and reduces the effect of variation in surface conditions and skidding. Using adequate delineation, good marking helps the driver to be aware of the road ahead. Using shoulder rumble strips reduces the effect of runoff crashes when the driver diverts their direction. Using street lighting.to make the vision clearer at night. Using traffic calming and speed management devices such as cameras to prevent drivers from driving at high speed.	1	5
	Severity (crashworthiness) / Driver side and passenger side	Roadside objects	Installing safety barriers along the road at both the driver and passenger side at a distance of 10m from the edge of the pavement where there is no safety barrier Increase the width of the paved shoulder to 2.5 m.	0.924	
Head–on (LOC)	Likelihood (crash avoidance)	- Road condition - Skid resistance - Lack of street lighting - Poor delineation - Lack of speed management and traffic calming techniques	Resurfacing the pavement with adequate overlay improves the driving behavior and reduces the effect of variation in surface conditions and skidding. Using adequate delineation, good marking helps the driver to be aware of the road ahead. Using shoulder rumble strips reduces the effect of runoff crashes when the driver diverts their direction. Using street lighting.to make the vision clearer at night. Using traffic calming and speed management devices such as cameras to prevent drivers from driving at high speed.	1.2	5
	Severity (crashworthiness)	- Median type	Improve the median types to metal safety barriers along the road section	0	

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