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Risk Assessment of The Latifiya Expressway Segment Using a Proactive Approach

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Abstract

Road safety assessment is an essential step in the management of transportation projects. The proactive approach in the safety assessment considers the pre-construction stage to reduce the likelihood of road accidents. This research aims to assess the risk of road infrastructure in Iraq by applying the most recent methodology based on road features and supported traffic data. The selected methodology significantly contributes to enhancing a proactive approach to road safety and incorporating risk assessment in the planning and design stages of road projects. A segment of 15km from the beginning of the Latifiya expressway was selected for this study and assessed using the international road assessment program methodology. Data on road features and traffic were collected for this goal; where data on 38 aspects of road features is collected. The traffic data includes traffic volume and spot speed. Then these data were coded and processed using VIDA online web. The assessment results were presented for three road user groups: vehicle riders, pedestrians, and motorcyclists. The results showed that the assessed segment has a high-risk level; 1 to 3 stars for vehicle riders and 1 star for motorcyclists and pedestrians. Countermeasures were presented, and their efficiency was tested to raise the star rating for all road user groups to five stars.

Keywords: International Road Assessment Program; Risk Assessment; Road Rating; Road Safety; Proactive Approach; Highway No. 8

1. Introduction

The risk of road networks in Iraq has increased with the increase in the use of transportation networks. It is recognized as an important indicator of quantifying the service quality and sustainability of transportation networks [1]-[3]. It is not only considered as an aim of transportation studies [4] but also it has been incorporated as input criteria of transportation service assessment and decision-making [5]-[8], and as a target of implementations of new strategies and programs, Innovations of modern transport modes and conducting new analytical studies in transportation engineering [8]-[12].

A proactive approach to risk assessment of road segments is based on road and traffic operational indicators. Its primary function is to incorporate road safety assessment in the planning and design stages of transportation projects in such a way that reduces the likelihood of crashes in the operation stages [13]-[14]. The indicator based on road attributes and predicted traffic conditions are used as a proactive measure; the International Road Assessment Program (iRAP) is an example of road assessment in a proactive approach [15].

The International Road Assessment Programme (iRAP) is a nonprofit organization that has been established to save lives by reducing dangerous roads everywhere in the world. The iRAP methodology of safety level assessment is a validated methodology developed by the iRAP agency based on road attributes and traffic operation parameters. The outputs of this methodology are in the form of a star rating, the safest roads are those with a 5-star rating (in green), and the least safe are those with a 1-star rating (in black) [15]. Kowtanapanich et al., [16] found that the iRAP indicator is a kind of subjective measure that is not based on crash data. Subjective performance measures are recommended as a replacement for objective data which is difficult to obtain, especially in developing countries where there is no organized and official database. To find out what could be done to reduce road trauma, Lee, et al. [17] decided to conduct an iRAP assessment of their strategic routes along just over 500 km of Brunei's network. They discovered that 65% of highways and 45% of all roads (both urban and rural) received a three-star rating. Hoque et al. [18] also used the iRAP methodology and real accident data to evaluate Bangladesh's severity and risk sections. In this study, it was observed that sections with rapid increases in star rating scores had greater crash rates than sections with gradual increases. This highlights the significance of having consistent star ratings (at least 3 stars) along the entire road. Implementing targeted road safety improved the length of the road rated 3-star or above, according to the case study conducted by Bhavsar et al. [19] for two roads, one in the state of Karnataka and the other in Gujarat. They discovered that there has been a 54 percent decrease in fatalities and a 42 percent decrease in injuries on the road in Gujarat, where vehicle occupants increased from 35 to 98 percent and motorcyclists from 24 to 80 percent. In Karnataka, where pedestrians increased from just 1 to 79 percent, there has also been a 54 percent decrease in deaths.

In Iraq, there have been a few attempts to develop a road safety index that can be used in identifying black-spot. In 2002, Ewadh [20] developed a road safety index for rural roads based on road features. Its validation is tested and demonstrated by comparing the results of sites ranking according to the developed index with the results of ranking according to conventional performance measures such as crash frequency and Equivalent Property Damage Only (EPDO) measure. In 2008, Neham and Ewadh [21] used the measure of an aggregated traffic conflict index at four leg-signalized intersections to analyze the risk level. This index was developed by incorporating volume data, spot speed**,** and some geometric characteristics. A significant relationship was found between the conflict frequency and traffic volume, and with the geometric features of intersections. In 2019, Abdul-Majeed and Ewadh [22]-[23] developed a conflicts-based measure using more geometric features of intersections to use in screening eleven-signalized intersections in Baghdad City and to identify the high-risk intersections. The results of ranking were compared with the results of ranking according to the crash rate measure. In 2020, Jameel and Al-Nuaimi and Jameel et al. [24]-[25] used the iRAP methodology to assess two road sections in Iraq based on 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. Shokat and Jameel [12],[26] used iRAP in assessing Expressway No. 1, Road project No. 9 (R9) to evaluate the effectiveness of the rehabilitation project and measure to what extent the safety level has been improved after the implementation of intervention options. They identified the crashworthiness and avoidance factors to distinguish between the risk factors of the likelihood of a crash occurring and of their severity [12]. This work has been carried out to investigate the application of valid methodologies of road safety analysis and assessment based on road features only. So, the main aim of this research is to assess the road safety of road infrastructure in Iraq using the proactive approach by applying the most recent methodology of risk assessment based on road features and supported traffic data on testing the risky spots.

The selected methodology has a significant contribution to the enhancement of the proactive approach to road safety and incorporating risk assessment in the planning and design stages of road projects.

2. The Methodology of the Research

The steps shown in Fig. 1 are taken to achieve the study's objectives. The first step is selecting the study area and collecting the needed data which includes the road features and the supported traffic data. Then, the selected road section will be assessed using the iRAP methodology. Based on the results of this step, road attributes risk factors will be identified to propose countermeasures. The risk assessment will be repeated after applying the proposed countermeasures to evaluate their effectiveness in improving the safety level and select the final set of countermeasures.

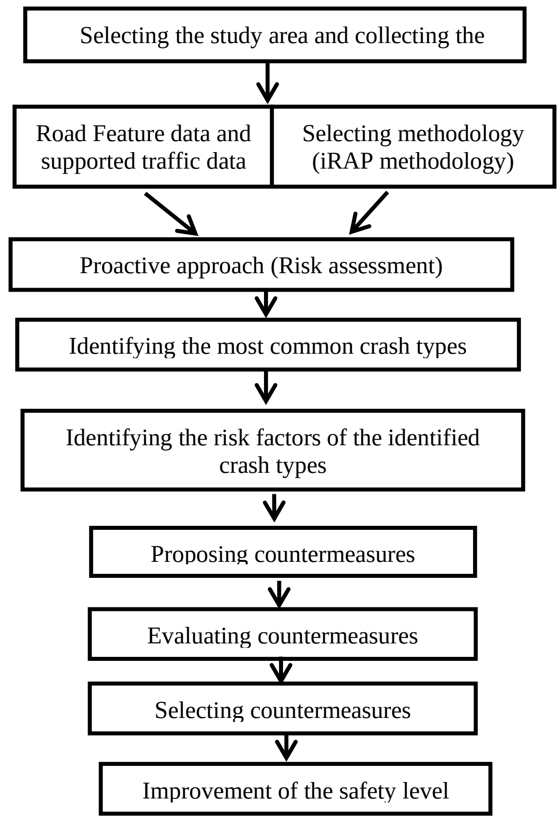


Figure 1. The Main Steps of the Research

3. The Study Area

The case study is part of Highway No.8 which extends from Baghdad through Al-Hilla, Samawah, Nasiriyah, and Basra to the Kuwait frontier. It is located in the Latifiya district in Babil Governorate, which is a sub-district of the Mahmudiyah district. The selected section is a 15 km section starting from Latifiya lat.32.9849-long44.3567 to the south of Haswa at lat.32.5230-long 44.2307, shown in Fig. 2.

4. Site Inspection and Data Collection

In this step, data related to road features and traffic characteristics were identified according to the input of the iRAP methodology.

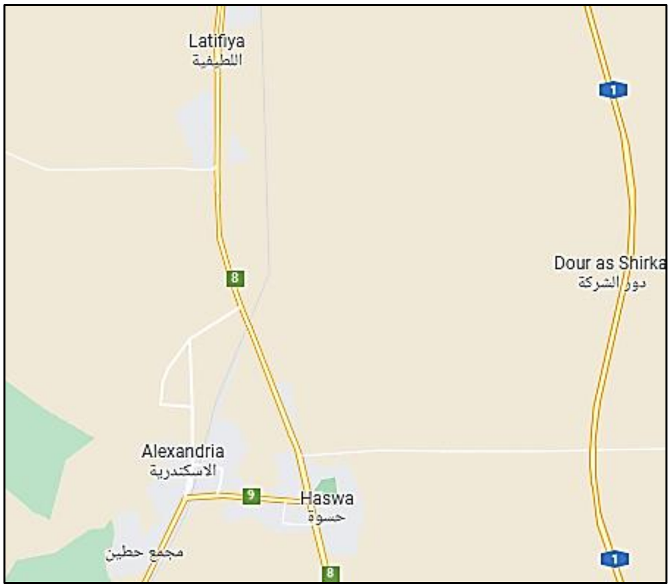


Figure 2. Study Area Definition for iRAP Assessment

4.1. Road feature attributes

The road feature data were collected for each 100m segment and shown in Table 1.

It includes cross-sectional characteristics, vertical profile, surface conditions, furniture and delineation, and others. Regarding the elements of a cross-section, the road section has two lanes per direction, each lane width of 3.25m. The median type was varied, some sections were raised physical type and some sections were barriers. The longitudinal grade of the selected highway section is less than 4%. The road was newly paved with flexible pavement and had a medium grip surface. In addition, there is no street lighting or special pedestrian crossing. The road furniture and delineations, land use, and area type are also recorded for each section.

4.2. Traffic Volume

Traffic volume data was collected manually for seven days including weekdays and weekends, from Tuesday 24/05/2022 to Monday 30/05/2022 as shown in Table 2. The recording of traffic volume was according to the most common traffic compositions, which are passenger cars (PC) and heavy vehicles (HV). The heavy vehicles are converted to passenger car units using an equivalent factor of 1.5 [27]. Equation 1 is used to compute the ADT for each section:

$$ADT = \sum Vi/n \tag{1}$$

Where i is the day of collecting the traffic volume, n = is the number of days, and Vi collected the total traffic volume on the day i.

4.3. Speed Data

Three measures of speed are required to assess the risk level of the chosen road segment which are speed limit, operating speed (85th percentile speed), and median speed (50th percentile speed). According to the post speed limit, the speed limit is 110 km/h. Regarding the operating and median speed, spot speed has been recorded for 1271 vehicles chosen randomly. The required calculations were performed to generate cumulative frequency distribution curves for the obtained spot speed data, as shown in Fig.3, to determine the 85th and 50th percentile speeds, as shown in Table 3.

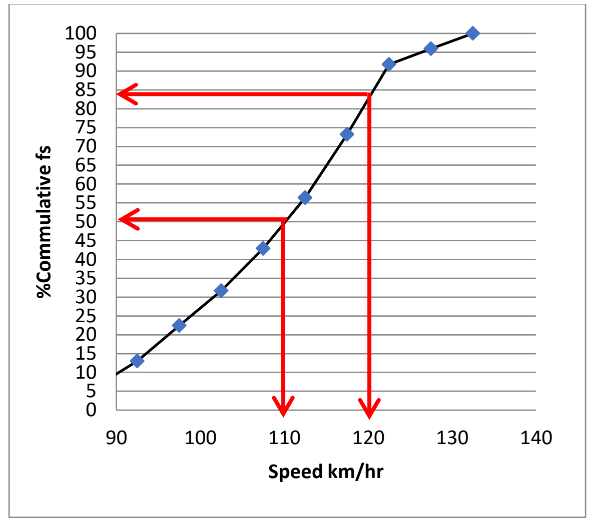


Figure 3. Cumulative Frequency Distribution Curve for Spot Speed Data

5. Data Coding and Processing

Road feature coding is the core of the iRAP project; its purpose is to use the data collected during the survey or road design to catalog the road features according to the iRAP coding manual. The iRAP coding manual [28] was used in this step. For example, code 1 for the carriageway attribute means that the carriageway type is divided into two directions; while for motorcyclists, pedestrians, and bicyclists flow, the code of "1" means the flow is 0. Excel form to be uploaded in the VIDA, the iRAP's web application, for the data processing step. To get the results of the assessment, data are processed using the VIDA website The processing is carried out in two stages, star rating scores calculations and star rating determinations [29].

5.1 Star Rating Scores (SRS) Calculations

The first stage is calculating the star rating scores (SRS) for each 100m road segment, the results are four SRSs for the four road user groups [29]. The SRS is an index developed to measure the risk level and used to determine the star ratings (SRs) in further steps. For each road user group, the SRS is computed for the crash types related to this road user group. For example, the SRS for the vehicle occupant is the summation of the SRS for five crash types; they are run-off crashes, head-on crashes (loss of control), head-on (overtaking), intersections crashes, and property access crashes. The crash types for motorcyclists are the same as the types of vehicle occupants in addition to the long type. The crash types for pedestrians and bicyclists are different than for vehicle occupants

Table 1. The Road Attributes of the Latifiya Expressway Section.

Road attributes	**Category selection**
Cross-sectional and roadside characteristics	
Carriageway	Divided 4-lane Highway
Number of lanes	Two per direction
Lane width	Wide ≥3.25m
Median type	0-2km safety Barrier-Metal; 2-6.5km Physical 5 to <5m width; 6.5-15km Safety barrier-Metal
Paved shoulder- driver-side	None
Paved shoulder-passenger-side	Medium >1m to <2.4m
Roadside severity-passenger-side object	1 to <5m
Roadside severity-driver-side distance	0-2km Safety barrier-metal; 2-15km Tree >=10cm diameter
Roadside severity-driver-side-object	1 to <5 m
Service road	Not present
Intersections and Property **Access Point**	
Intersection type	None
Intersection road volume	Not applicable
Intersection channelization	Not present
Intersection quality	Not applicable
Property access point	0-6km None; 6-9km Residential Access<3; 9-15km None
Vertical and horizontal alignment	
Curvature	1-8km Gently curve; 8-8.5km moderate; 8.5-15km Gently Curve
Quality of curve	1-8km (Not applicable); 8-8.5 km (poor); 8.5-15km (Not Applicable)
Grade	≥0% to <4%
Road surface conditions	
Road condition	Good
Skid resistance	Sealed-medium
Furniture	
Delineation	Poor
Street lighting	Not present
Centerline rumble strips	Not present
Shoulder rumble strips	Safety barrier-metal
Pedestrian and two-wheel occupant facilities	
Pedestrian crossing facilities on the road	No facility
Pedestrian crossing quality	Not applicable
Pedestrian fencing	No facility
Sidewalk-driver-side	None
Sidewalk-passenger-side	None
Motorcycle facility	None
Bicycle facility	None
Others	
Land use (both sides)	Undeveloped area
Speed limit	100km/h
Area type	Rural
Differential speed limit	Present
Speed management	Not present
Roadwork	No roadwork
Sight distance	Adequate

Table 2. Data Collected for Traffic Volume

Day and Date	**HV**	**PC**	**Total = PC +1.5(HV)**
Tuesday, 24/5/2022	3770	4901	10556
Wednesday, 25/5/2022	3850	4620	10395
Thursday, 26/5/2022	3580	6982	12352
Friday, 27/5/2022	4040	5656	11716
Saturday, 28/5/2022	4150	5395	11620
Sunday, 29/5/2022	4655	5586	12569
Monday, 30/5/2022	3680	4784	10304
ADT=11359			

Table 3. The Analysis of Spot Speed Data.

Speed class (Km/hr.)	Mid-class value (s) (km/hr.)	Observed frequency (*f*)	*f**s	% *f**s	Cumulative % *f**s
85-<90	87.5	98	8575	6.164	6.164
90-<95	92.5	103	9527.5	6.849	13.012
95-<100	97.5	135	13162.5	9.461	22.474
100-<105	102.5	125	12812.5	9.210	31.684
105-<110	107.5	145	15587.5	11.205	42.888
110-<115	112.5	167	18787.5	13.505	56.393
115-<120	117.5	199	23382.5	16.808	73.201
120-<125	122.5	211	25847.5	18.580	91.780
125-<130	127.5	45	5737.5	4.124	95.905
130-<135	132.5	43	5697.5	4.095	100.000
Total		1271	139117.5		

Likelihood refers to the road attributes that have roles in increasing the probability of crash occurrence while severity refers to the road attributes that have roles in increasing the severity of crashes when they occur. For example, the likelihood of run-off crashes for vehicle occupants may be influenced by lane width, curvature, quality of curve, delineation, street lighting, road condition, grade, and skid resistance. The severity of the same crash type is influenced by the roadside objects and distance to roadside objects. The SRS for individual road user (i) groups can be calculated using equation 2 [15].

$$SRSi = \sum \text{Crash Type Scores} \qquad (2)$$

It can be seen that the SRS for vehicle occupants is zero for all head-on crashes because of the existence of a median along the road section which prevents the changes of vehicles directly to the opposite directions. The SRS for intersections and property access are zero also because they are excluded in this study and the focus is only on the road segments. The SRS for run-off crashes (when the drivers depart from the lane due to loss of control or overtaking) is 6.19 and 5.14 for the driver's side and passenger sides respectively. The total SRS is 11.33. For Motorcyclists, the total SRS is the summation of the SRS for run-off crashes in both directions, and the SRS for motorcyclists traveling along the road, the total SRS is 37.54.

For pedestrians, the peak hour pedestrian flow along the road was higher in segments 4 and 7 which resulted in higher SRS for along crash type in these segments. It is noted also that the SRS for crossing pedestrians is zero in the side road because there is no pedestrian flow in these segments. For bicyclists, the SRS is zero for all crash types because the bicyclist's flow is zero along the road section. The total SRS is then smoothed by averaging the total SRS by a specific length, 3 km, and by selected sections when there are bends or intersections.

5.2 Star Ratings (SR) Determinations

The star rating (SR) is determined in this step to give a subjective interpretation of the risk level of the road section. Five-star ratings are used to classify the risk level into five levels; five stars reflect the safest level while one star reflects the lowest safety level. Table 4 shows the iRAP SR bands which are used for this purpose.

Table 4: Star Rating bands and colors [15]

SR	SRS		
	Vehicle Occupants and motorcyclists	Bicyclists	Pedestrians
5	0 to <2.5	0-<5	0 to <5
4	2.5 to <5	5 to <10	5 to <15
3	5 to <12.5	10 to <30	15 to <40
2	12.5 to <22.5	30 to <60	40 to <90
1	> 22.5	> 60	> 90

For illustration, the total SRS for vehicle occupants, 11.33, is located between 5 and 12.5 producing an SR of 3. The smoothed SRS, 19.591, produced an SR of 2. It can be seen in Table 5 that vehicle occupants' SRs are between 1 and 3 reflecting the highest-risk level to moderate risk level. While the SR for the other road user groups is 1 reflecting the highest risk level. The smoothed star rating results are presented also in risk map forms, in which the results are presented in colors form that is illustrated in Table 5, green color reflects the safest conditions with five-star ratings (SRs), yellow color represents four SRs, orange color represents three SRs, red color represents two SRs and black color reflects the most dangerous level with one star only.

Four risk maps are produced for the assessed site, each for an individual road user group which are vehicle occupants, motorcyclists, pedestrians, and bicyclists as shown in Fig.4.

6. Discussion of the Risk Assessment Results

6.1. Vehicle Occupants

- About 9 km, which is about %60 of the assessed road section, has been rated with 3 stars while the remaining segments were rated 1 star only.

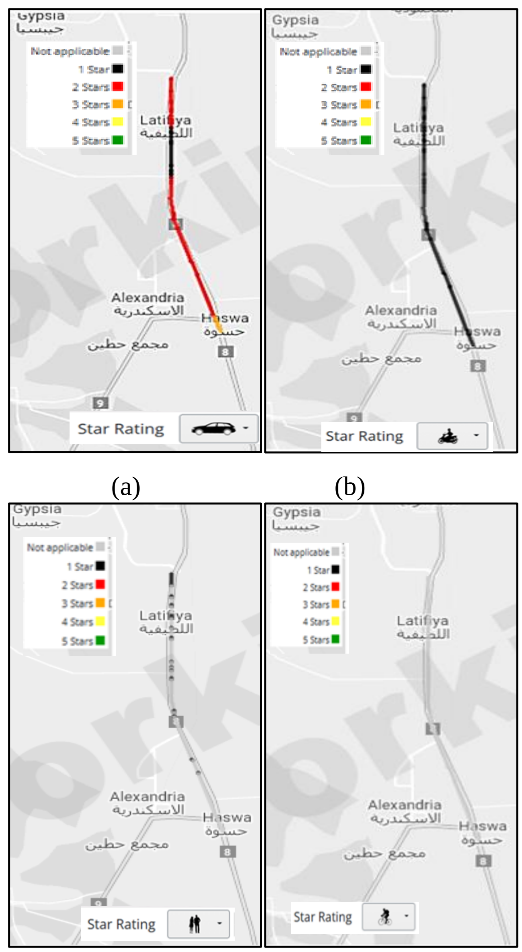
Table 5: The SRS results at the existing conditions

Vehicle SRS (All segments)										
Run-Off LOC Driver-Side	Run-Off LOC Passenger-Side	Head-On LOC	Head-On Overtaking	Intersection	Property Access	Total	Total Smoothed	Star Rating Raw	Vehicle Star Rating Smoothed	
6.193152	5.140316	0	0	0	0	11.33347	19.591	3	2	
Motorcyclist SRS (All segments)										
Run-Off LOC Driver-Side	Run-Off Passenger-Side	Head-On LOC	Head-On Overtaking	Intersection	Property-Access	Along	Total	Total Smoothed	Star Rating Raw	Star Rating Smoothed
17.69472	14.68662	0	0	0	0	5.16	37.54134	43.43958	1	1
Pedestrian SRS										
Segment	Along	Crossing Intersecting Road (side road)	Crossing Inspected Road	Total	Total Smoothed	Star Rating Raw	Star Rating Smoothed			
1-3	127.575	0	110.8013	238.3763	248.041	1	1			
4	148.8375	0	110.8013	259.6388	248.041	1	1			
5	127.575	0	110.8013	238.3763	248.041	1	1			
6	127.575	0	110.8013	238.3763	248.041	1	1			
7	170.1	0	110.8013	280.9013	248.041	1	1			
8	127.575	0	110.8013	238.3763	248.041	1	1			
15	127.575	0	110.8013	238.3763	248.041	1	1			
Bicyclists SRS (All Segments)										
	0	0	0	0	0	0	0			

- The highest SRS is for run-off crashes because the road attribute risk factors have high scores. From reviewing these attributes on the assessed road section, it can be noted that segments 21-66, 88-90, and 101-103 have high road-side severity objects from the driver's side in the median, where trees with a diameter greater than 10 cm are existence along these segments with a distance between 1m to 5m from the pavement edge. The existence of a metal safety barrier from the passenger side at a distance of 1m to 5m also raises the risk factors in these segments. The remaining segments have lower risk factors resulting from the existence of metal safety barriers at a distance of 1m to 5 m from the edge of the pavement.
- The absence of a paved shoulder on the driver's side is also another factor in increasing the severity SRS of run-off crashes.
- There other road attributes that resulted in increasing the likelihood of run-off crashes are the lack of shoulder rumble strips, poor delineation, lack of street lighting, and moderate skid resistance of the road surface.

The road design standards meet the safety requirement to avoid the severity of head-on crashes because the assessed road is divided by a median.

However, the risk factors of the likelihood of head-on crashes, such as the narrow lane width (between 2.75m and 3.25 m), lack of shoulder rumble strips, poor delineation, lack of street lighting, and moderate skid resistance of the road surface may lead to a head-on crash due to loss of control.



(a) (b) (c) (d)

Figure 4: Risk assessment results of Latifiya expressway (existing conditions): (a) vehicle occupants, (b) Motorcyclists, (c) Pedestrians, (d) Bicyclists

6.2. Motorcyclists

- The star rating is 1 along the road section. The highest SRS resulted in segments 82 to 86 because of the existence of curvatures.

- The highest SRS is for run-off crashes. The road attribute factors of vehicle occupants are the same factors that lead to an increase in the SRS of run-off crashes for motorcyclists.
- The along crashes have also high SRS because of the lack of motorcyclist facilities in the assessed sections.
- The zero head-on SRS is also recorded for motorcyclists because of the existence of a median along the road sections.

6.3. Pedestrians

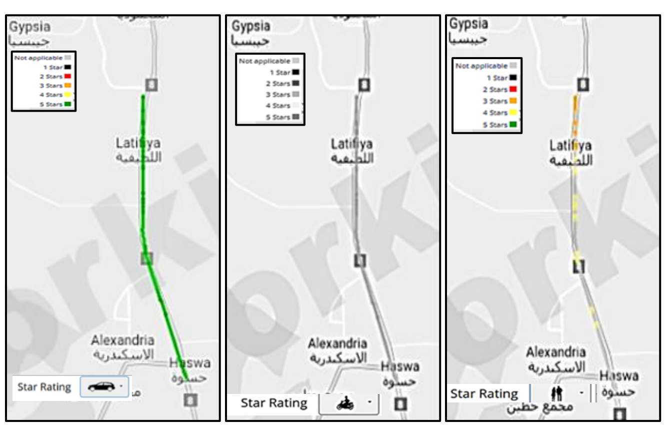
- Only 22 segments (about 2.2 km) were rated because the pedestrian flow along and across the road section was observed in these segments only. These segments are rated with 1 star only, while the star rating is not applicable in the remaining segments because there is no entered pedestrian flow. The inapplicable segments are colored with grey color as shown in Fig. 4 c.
- The diagnosed crash types are along, crossing the assessed road, and crossing the side road. The main road attribute factor that has a role in increasing the severity of alone crashes is the absence of a sidewalk while the main factor in increasing the severity of crossing crashes is the absence of crossing facilities.
- The other road that attributes resulted in increasing the likelihood of all types of pedestrian crashes are the lack of pedestrian fencing, shoulder rumble strips, poor delineation, lack of street lighting, and moderate skid resistance of the road surface.
- The lack of speed management and traffic control devices and facilities has also been a factor in pedestrian crash likelihood. This feature can reduce the operating speed by 5km/h to 10km/h below the speed limit. They may include curb build-outs, speed humps, raised tables, and speed cameras.

7. Proposing Countermeasures

Based on the identified risk factors, countermeasures can be proposed to reduce the risk level. The iRAP methodology produced countermeasures with estimated effectiveness in reducing the risk level and the cost rating. The proposal contains 16 single countermeasures as shown in Table 6. In the proposal, the roadside hazard is taken into account to reduce the severity of run-off crashes for vehicle occupants and motorcyclists by proposing removing the trees with a diameter greater than 10cm that are located in a distance of less than 5 m and increasing the distance between 5m to 10m by adding paved shoulder on the driver side with width between 1m to 2.4m. The distance to the metal safety barrier installed on the passenger side is also proposed. These countermeasures can reduce the severity of crashes when they occur by 25% to 40% with a cost rate medium in comparison with the cost of other countermeasures.

8. Evaluating the Proposed Countermeasures

The proposal is subjected to evaluation according to effectiveness and cost. The effectiveness is fixed by determining the change in SRS and SR of the assessed sections after the implementation of the countermeasures in the proposal. Fig. 5 shows the risk maps of the assessed road section after applying the proposal, and Table 7 shows the results of SRS and SR after applying the proposal. Table 8 shows the percentages of reduction in the SRS and the percentage of upgrade in the SR resulting from applying the proposal of improvement. It can be seen that applying the proposal has resulted in upgrading the SR for vehicle occupants to 5 stars with a significant reduction in the SRS of about 84.25%, reflecting the high effectiveness level of the proposed treatment. The SR rating for motorcyclists has been upgraded to 3 stars, which is the minimum SR required by the iRAP agencies while a significant reduction in the SRS of about %81.24 has resulted from applying the proposal. For pedestrians, the star rating is between 3 and 4 stars with an average reduction in the SRS of about %94.72.



(a) (b) (c)

Figure 5. Risk assessment results of Latifiya expressway after applying proposal: (a) vehicle occupants, (b) Motorcyclists, (c) Pedestrians

Table 6: Proposal for improvement of the safety level of the assessed road section

	Countermeasure	Outcomes		Effectiveness	Cost rating
		Attribute	Category		
1	Removing the roadside objects, trees with a diameter >=10cm which are located at a distance less than 5 m from the driver and passenger sides	Roadside Severity - Passenger Side Distance	5 to <10m	25-40%	Low to medium
		Roadside Severity - Passenger Side Object	Tree >=10cm		
2	Increasing the distance of the metal barrier on the passenger side	Roadside Severity - Passenger side Distance	5 to <10m	25-40%	Low to medium
3	Shoulder sealing on the driver side and passenger with a width greater than 1m and less than 2.4m	Paved shoulder	Medium 1m to <2.4m	25-40%	Medium
4	Installing Shoulder rumble strips	Shoulder Rumble Strips	Present	10-25%	Medium
5	Installing street lighting	Street Lighting	Present		
6	Improving Delineation	Delineation	Adequate	10-25%	Low
7	Pave road surface	Skid Resistance / Grip	Sealed - adequate	25-40%	Low to medium
8	Motorcycle Lane (Painted logos only on- the road)	Facilities For Motorized Two-wheelers	Inclusive motorcycle lane on a roadway	25-40%	Medium
9	Footpath provision passenger side (adjacent to the road)	Sidewalk - Passenger Side	Non-physical separation path<1m	40-60%	Low to medium
10	Footpath provision driver side (adjacent to the road)	Sidewalk - Driver Side	Non-physical separation informal path 0m to <1.0m		Low to medium
11	Unsignalized crossing	Pedestrian Crossing - Inspected Road	Unsignalized marked crossing with refuge	25-40%	Low
12	Upgrade pedestrian facility quality	Pedestrian Crossing Quality	Adequate		Low to medium
13	Pedestrian fencing	Pedestrian Fencing	Present	25-40%	Low
14	Traffic calming	Speed Management / Traffic Calming	Present	25-40%	Medium to High
15	Speed management reviews	Operating Speed (85Th Percentile)		25-40%	Medium

Table 7. The results of iRAP processing after applying the proposal

Vehicle occupants

Segments	SRS Run-Off LOC Driver-Side	SRS Run-Off LOC Passenger-Side	SRS Head-On LOC	SRS Head-On Overtaking	SRS Intersection	SRS Property Access	SRS Total	Star Rating Raw
1-150	0.892416	0.892416	0	0	0	0	1.7848	5

Motorcyclist

Segments	SRS Run-Off LOC Driver-Side	SRS Run-Off Passenger-Side	SRS Head-On LOC	SRS Head-On Overtaking	SRS Intersection	SRS Property-Access	SRS Along	SRS Total	Star Rating Raw
1-150	2.23104	2.23104	0	0	0	0	2.58	7.04208	3

Pedestrian

Segments	SRS Along	SRS Crossing Intersecting Road	SRS Crossing Inspected Road	SRS Total	SRS Total Smoothed	Star Rating Raw
1-8	0.216	0	20.5632	20.7792	20.7792	3
15, 20, 26-27,	0.216	0	20.5632	20.7792	20.7792	3
33, 39, 53, 58, 112	0.216	0	20.5632	20.7792	16.66656	3
56	0.216	0		0.216	16.66656	4
63	0.216	0		0.216	13.9248	4
82, 85	0.216	0	20.5632	20.7792	13.9248	3
112	0.216	0	20.5632	20.7792	10.4976	3
120	0.216	0			10.4976	4

Table 8. The percentage of changes in the SRS and SR after applying the proposal for improvement

Vehicle SRS					
Total SRS before improvement	Total SRS after improvement	% Reduction in SRS*	Star Rating Raw before improvement	Star Rating Raw after improvement	% Upgrade in SR**
11.33347	1.784832	84.25%	3	5	40%
Motorcyclist SRS					
Total SRS Before improvement	Total SRS after improvement	% Reduction in SRS*	Star Rating Raw before improvement	Star Rating Raw after improvement	% Upgrade in SR**
37.54134	7.04208	81.24%	1	3	40.00%
Pedestrian SRS					
Total SRS Before improvement	Total SRS after improvement	% Reduction in SRS*	Star Rating Raw before improvement	Star Rating Raw after improvement	% Upgrade in SR**
247.4888	13.068	94.72%	1	4	60%

$^{*}\%\ reduction\ in\ SRS = \frac{SRS\ before - SRS\ after}{SRS\ before}$, $^{**}\%\ reduction\ in\ SR = \frac{SR\ after - SR\ before}{5}$

9. Conclusion and Recommendation

The results of the risk assessment of the selected case study showed that vehicle occupants and vulnerable road users including motorized two-wheeled vehicles and pedestrians have high-risk levels, with results of a star rating of 3 for vehicle occupants and 1 for both motorcyclists and pedestrians.

The run-off crashes had the highest star rating scores among the crash types considered by the iRAP methodology for vehicle occupants and motorcyclists. The main factors that increase the severity of run-off crashes are roadside objects, big trees and metal barriers, and the lack of paved shoulders. The main factors that increase the likelihood of run-off crashes are inadequate lane width, lack of lighting, poor delineations, lack of shoulder rumble strips, skid resistance, and lack of speed management reviews. These factors are considered in proposing the countermeasures for upgrading the safety level for vehicle occupants.

Motorcyclist-along crashes, pedestrian-along crashes, and pedestrians crossing crashes have high star rating scores. The main factors are the lack of related facilities, such as crossing facilities, pedestrian footpaths, pedestrian fencing, and motorcyclist paths.

Based on these results and the identified contributed risk factors, it is recommended to remove the roadside objects, add shoulder lanes, and use traffic signs, lighting, traffic calming, street delineation, and rumple strips. Furthermore, it is recommended to install pedestrian bridges, especially on highways, and rehabilitate the existing ones. These recommendations would upgrade the level of road safety to the highest level for all road users.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Author Contribution Statement

Abeer K. Jameel proposed the research problem and developed the methodology. Aya H. Jameel collected the data, processed them using the selected methodology, tabulated, and presented the results. Abeer K. Jameel supervised the findings of this work. Both authors discussed the results and contributed to the final manuscript.

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