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Assessing Road Safety of the Peshawar-Rawalpindi Section of National Highway (N-5) in Pakistan Using iRAP

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Abstract

The road safety situation in Pakistan is critical, with an average 25,781 fatalities due to road accidents. This study considered the N-5 national highway section between Rawalpindi and Peshawar, employing the International Road Assessment Programme (iRAP). The data collected reveals that many road sections in this area have low safety ratings, highlighting significant risks and substandard road conditions for travelers. Through the iRAP, proposed countermeasures were evaluated and analyzed for the purpose of improving safety ratings on N-5, in line with the Sustainable Development Goals (SDGs) for 2020–2030, targeting road safety performance goals 3 and 4. To meet the SDG target of having 75% of road segments rated 3 stars or higher, the study includes a comprehensive risk assessment and mapping, safety interventions, a Safety Rating Investment Program (SRIP), Fatal and Serious Injuries (FSI) Estimation, and Benefit-Cost Ratio (BCR) analysis. The findings stress the importance of a holistic approach, combining both geometric and non-geometric measures (such as pavement maintenance, traffic control devices, street lighting, school zone crossings, and clearing roadside hazards) to fully achieve global road safety objectives.

Keywords

sustainable development goals, road safety, iRAP, star rating, safer roads, benefit-cost ratio (BCR)

1 Introduction

Road traffic accidents are one of the alarming threats faced by humans around the world, 1.35 million people lost their lives due to traffic accidents (World Health Organization, 2018). Among 1.35 million, only in Pakistan 25,781 fatalities occurred (World Health Organization, 2015). More than 30 accidents per 10,000 registered vehicles happened due to which the fatality rate of the country remains highest among the world (Batool et al., 2011). In 75% of reported accidents, the age varies from 15 to 64 years, 1,461 people become disabled out of 100,000 people per year due to road traffic crashes (World Health Organization, 2009). Along with human life, those accidents have financial impact, which is over 100 billion Pakistani rupees annually (Ullah et al., 2021).

Many researchers conclude that due to the effective implication of international safety standards, the road safety standards can be improved (Shen et al., 2015). For instance, U.S. Vision Zero Cities demonstrates that through targeted strategies the fatality rate can be reduced (Ferenchak, 2023), Lahore Safe City project shows how Intelligent Transportation Systems (ITS) can improve traffic safety (Saleemi et al., 2022). iRAP is also one of the new innovations that is improving road safety worldwide (Kačan et al., 2020). The iRAP methodology was

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applied and used in Haryana to evaluate the safety of State Highway 11A, to collect speed, video and picture data for a 1 km road section of highway (Sunil and Sharma, 2021). Another studies use the iRAP for pedestrian facilities, paved shoulders, traffic calming, road crossings, and intersection enhancements to decrease the risk of the fatal injuries (Bhavsar et al., 2019), for the causality of fatal accidents (Krishnan, 2017). Studies used iRAP for pedestrian safety, to enhance sight distance, implement pedestrian fencing, and upgrade pedestrian facilities (Hu et al., 2016). Another study uses the same methodology to determine the relation between road safety and achieving sustainability (Bliss and Breen, 2012). Other studies use the iRAP to identify technical flaws in the road constructions (Soames Job, 2012). The international best practices in the country like Canada use it for the risk mapping strategy (Macangus et al., 2012), in the US the methodology is used to determine the existence or the lack of the roads according to the traffic flow and volume (Harwood et al., 2010), (Hossain and Medina, 2020). (Vecino-Ortiz and Hyder, 2014) critically assess the International Road Assessment Program's (iRAP) cost-benefit analysis methodology, specifically the calculation of the value of statistical life (VOSL) in road safety interventions.

Relationships between geometric countermeasures and safety standards are important to consider (Sil et al., 2020), numerous studies concluded that accident and highway geometric design have a strong correlation (Miaou and Lum, 1993), (Quezon et al., 2017). Road design, specifically a separate bicycle lane, and grid separation between road and cycle lane also increase safety between cyclists, pedestrian and vehicles (Li and Fernie, 2010). (Morrison et al., 2019), and likewise the installation of signal and warning system at the intersection and median (Lin and Mouratidis, 2013), (Montella, 2009), (Poullis and You, 2010), (Vignali et al., 2019). The roadside barriers and fixed objects could cause distraction of attention, (Bambach et al., 2013), shoulder sealing (Meuleners et al., 2011), (Sapkota et al., 2011), and obstruction at the sight distance (Glennon, 1940). Pavement life cycle can be improved (Gouveia et al., 2022), (Laiou et al., 2016) and technological application of pavement assessment can be done from smart phones as well (Alqaydi et al., 2021).

1.1 Scope and limitation

N-5 is the major transportation corridor, which connects Karachi ports with the border of Afghanistan, passing through major cities, i.e., Peshawar, Islamabad, Lahore, Multan, Hyderabad and Karachi. Most of the agriculture products, industries, and other consumer commodities are located along the N-5 corridor. Road transportation is the common mode of transportation in the country, where 94% freight, and 96% passenger transportation depend on the road. The total road network consists of 263,000 km, where 14,000 km are operated under National Highway and Motorway network, which is almost 4.6% of the total available roads, but in terms of traffic the N-5 carries approximately 65% of the traffic (Akhtar and Ministry of Communications, 2012). The current study focuses on the origin and destination points between Peshawar and Rawalpindi, as shown in Fig. 1. The overall research methodology adopted in this study is illustrated in Fig. 2. Similarly, the data was collected from the N-5 section, where the form used for counting is shown in Fig. 3, which indicates a diverse range of vehicles counted during the survey, including 2-wheelers (motorcycles), cars, 3-wheelers (rickshaws), and trucks. Fig. 4 presents the collection points

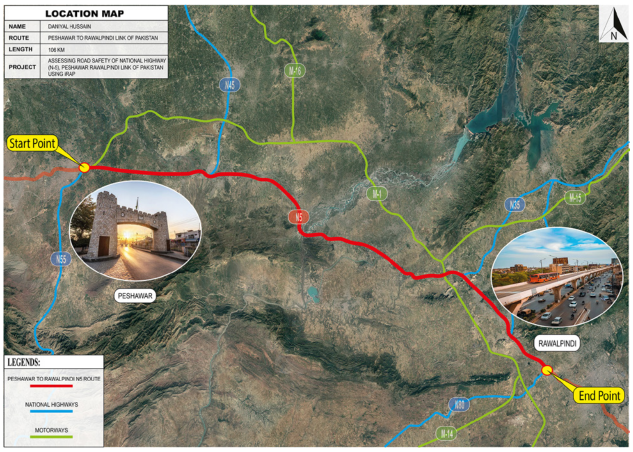


Fig. 1 Location map of manual traffic count survey points on N-5

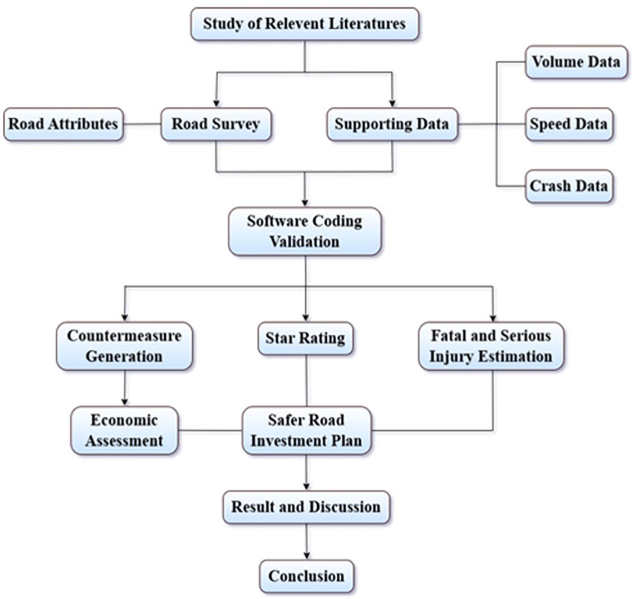
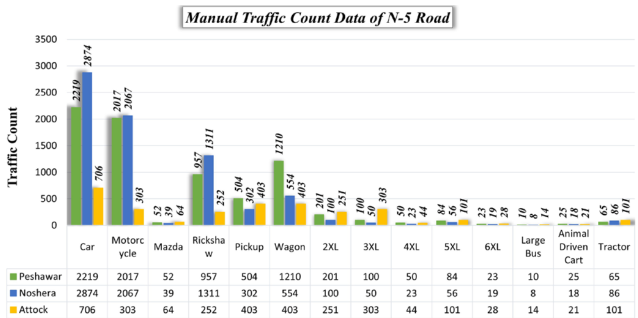


Fig. 2 Research methodology framework

Fig. 3 Manual counting form



	Car	Motorcycle	Mazda	Rickshaw	Pickup	Wagon	2XL	3XL	4XL	5XL	6XL	Large Bus	Animal Driven Cart	Tractor
Peshawar	2219	2017	52	957	504	1210	201	100	50	84	23	10	25	65
Noshera	2874	2067	39	1311	302	554	100	50	23	56	19	8	18	86
Attock	706	303	64	252	403	403	251	303	44	101	28	14	21	101

Fig. 4 Manual classified count for N-5

considered for the survey, between the section of the study passing through Peshawar, Nowshera and Attock city.

A study was also conducted to analyze the traffic flow, lane expansion, traffic management for N-5 corridor in Rawalpindi, Pakistan, while using SYNCHRO (Ali et al., 2015). Another study (Gulzar et al., 2012) stated that between 2000 and 2010 the same route had the highest number of accidents. To identify the accident trends (Abbas and Balkhyour, 2018) on N-5, the study concluded that weak organizational structure and non-affective road enforcement are also factors of the high risks. Most of the accidents weren't reported officially, (Baig et al., 2021), but the N-5 corridor is a risk-prone corridor. Pavement condition is also one factor of the accidents in Pakistan (Chen and Raza, 1998) and weak road crash audit and response has decreased the road safety (Ahmed et al., 2015).

2 Methodology

According to the United Nations (UN), as target goal for the period 2020–2030, 12 global safety targets are set as Sustainable Development Goals (SDGs). Global road safety performance targets 3 and 4 are set targeted for the current study. The study mainly focused on N-5 to evaluate and improve road safety conditions. A comprehensive methodology was developed, which includes collection of data from surveys, manual traffic counts, speed, roughness index, and traffic crash data. A 100 m section was considered with georeferenced analysis, and 52 attributes were selected for the iRAP assessment. The attributes consist of risk mapping, star rating, fatal injuries estimation, and geometric countermeasures were also aimed to enhance the safety condition of N-5 Road. To estimate the effectiveness of applied countermeasures, a comparison shall be drawn between the current situation and subsequent scenarios. The detailed analysis will provide the benchmark for the decision maker, regarding the current proposed situation and expected results after the implementation of the proactive approach.

2.1 Data collection

To assess road safety on the N-5 national highway, the following data were collected through field surveys.

2.1.1 Traffic data

The manual traffic count was carried out from 09.00 am to 05.00 pm, as the previous research identified this period as the peak hours for the Peshawar city (Farooq et al., 2021). The survey also concluded that motorcycles and cars are the predominant vehicles passing through the section; a finding, which is consistent with the previous study (Ullah et al., 2021), where the other types of vehicles were also counted, such as wagons, rickshaws and pickups. The complete data set is shown in Fig. 4.

2.1.2 Speed data

Speed Data can be used for identifying the high-speed zone where the accident risk increases due to excessive speed (Zhang et al., 2022). During the survey, the speed data were collected through SpeedPro app (SpeedPro, 2025) along with GPX technology to measure vehicle operating speeds on the road, over 100 m segments, the data were collected from 1,060 different road segments, the results of which are presented in Fig. 5. The speed data collected from the survey states that overall average speed was 46.4 km/h,

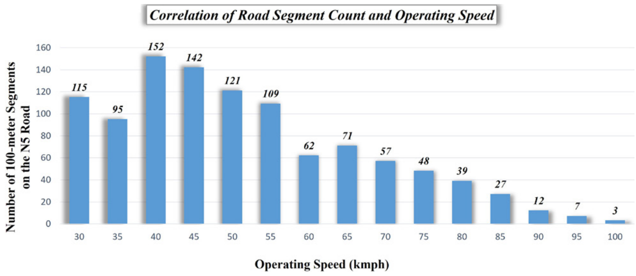


Fig. 5 Correlation of road segment count and operating speeds on N-5

the maximum speed was recorded as 101.7 km/h, and minimum speed as 5 km/h.

2.1.3 IRI data

The international roughness index (IRI) was measured from the longitudinal road profiles through road bounce app. The significance of the IRI in terms of road assessment plays a huge role, so that we can analyze how safer the road is for the road users while driving. According to the distribution of riding quality, as shown in Fig. 6, 27% of the roads are in good condition, while 48.77% are in the average category, and 24.23% in the poor category.

2.1.4 Georeferenced images

The Georeferenced image data set was generated through SpotLens app (SpotLens, 2025) using GPX, the image was connected from origin to destination, while specific geographic locations were specified between starting and ending points of the N-5 section. Through the Georeferenced image, it provides guidance in the recognition of critical road aspects required for the comprehensive road safety analysis necessary for the attribute coding. The use of SpotLens app along with GPX increases the accuracy of relevant collected data for the detailed analysis and assessment through the section. In Figs. 7 and 8, images consist of latitude, longitude, chainage and Roughness index for 100-meter road segments. The images clearly display comprehensive data collection from every segment, while

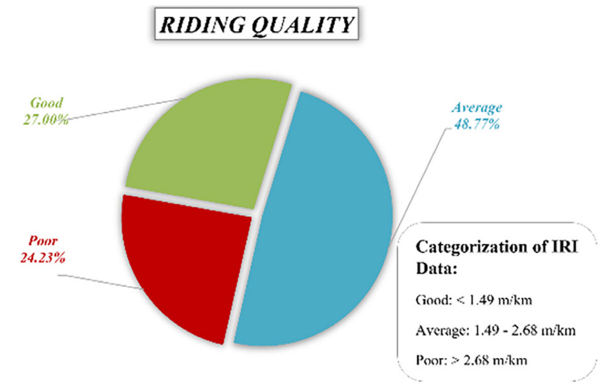


Fig. 6 Distribution of riding quality on N-5

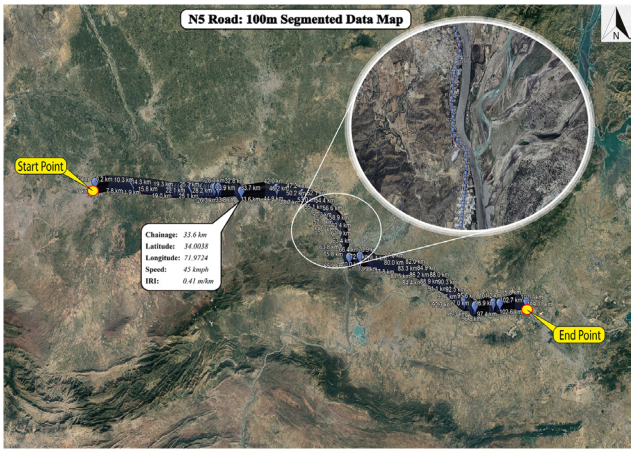


Fig. 7 N-5 Road: 100 m segmented data map

Fig. 8 Georeferenced images of N-5

providing detailed geographically aligned points. For the detailed survey and analysis, a total of 1,060 georeferenced images with 52 attributes were selected and gathered on the N-5 sections.

2.1.5 Accidents data

The accidents data were collected from the National Highway Police from 2015 to 2019, consisting of crash type, run-off events, head-on collisions during overtaking maneuvers, head-on line of sight crashes, intersection-related incidents, property access points and others. Through the analysis, comprehensive accident trends were identified, to evaluate road safety conditions, through iRAP assessment, assisting in the development of effective countermeasures to improve safety and mitigate potential hazards, as shown in Table 1.

2.2 Selection criteria

The selection of the 14 geometric countermeasures followed a rigorous process, considering both financial viability and effectiveness. The iRAP Software (International Road Assessment Programme (iRAP), 2023)

Table 1 User group distribution by crash type

User Group Distribution / Crash Type	Vehicle Occupant		Motorcyclist		Pedestrian		Bicyclist	
	Percentage (%)	Fatalities	Percentage (%)	Fatalities	Percentage (%)	Fatalities	Percentage (%)	Fatalities
Run-off LOC driver-side	8.90	17	1.22	1	NA	NA	NA	NA
Run-off LOC passenger-side	4.19	8	7.32	6	NA	NA	NA	NA
Head-on LOC	1.05	2	21.95	18	NA	NA	NA	NA
Head-on overtaking	30.89	59	14.63	12	NA	NA	NA	NA
Intersection	13.61	26	29.27	24	NA	NA	100.00	5
Property access	17.28	33	NA	NA	NA	NA	NA	NA
Along	NA	NA	NA	NA	NA	NA	NA	NA
Crossing intersected road	NA	NA	NA	NA	12.20	5	NA	NA
Crossing inspected road	NA	NA	NA	NA	9.76	4	NA	NA
Other	24.08	46	25.61	21	78.05	32	NA	NA
Total	**59.88 %**	**191**	**25.71 %**	**82**	**12.85 %**	**41**	**1.57 %**	**5.00**

NA = Not applicable

was used for selection, prioritizing cost-effectiveness to ensure practical interventions for enhancing road safety. For instance, cost-efficient options were prioritized, especially when multiple countermeasures showed potential in reducing fatalities in specific areas. Through iRAP validation, all 52 road attributes were meticulously evaluated using images to assess current conditions. The software employed countermeasure triggers to determine which measures could be applied to specific locations, guiding the selection process accordingly. Practical considerations further guided the selection, with measures like bicycle lanes on road addressing increasing cyclist traffic and delineation and signing at intersections improving motorist visibility. Upgraded curve delineation, refuge islands, roadside barriers, shoulder sealing, improved sight distance, and unsignalised raised crossings were strategically chosen to address various safety concerns, ensuring a comprehensive approach to enhancing road safety.

Star ratings are calculated from the "Star Rating Scores" (SRS) and are thus used to compute the different risk levels. These scores are computed by the combination of multiple relative risk factors. These ratings are then presented in the form of maps, charts, tables and risk worm diagrams etc. For every 100 m segment of the road, an SRS is calculated for the four different categories, i.e., commuters, motorcyclists, pedestrians, and cyclists.

The iRAP rating standards range from 1 to 5, where 5 indicate safe, denoted with green, 4 indicates below the safe, and denoted with yellow, 3-star rating is denoted with orange, 2 stars with red and 1 star rating is associated with the most hazardous situation. For the iRAP data set, a 100 m road segment was considered throughout the section.

3 Results

The results are given below, which show significant safety improvements on the road N-5 with reduced accident rates after implementing the proposed countermeasures.

3.1 Star rating map

The star rating maps are included in this analysis, Fig. 9 illustrates the safety ratings before and after

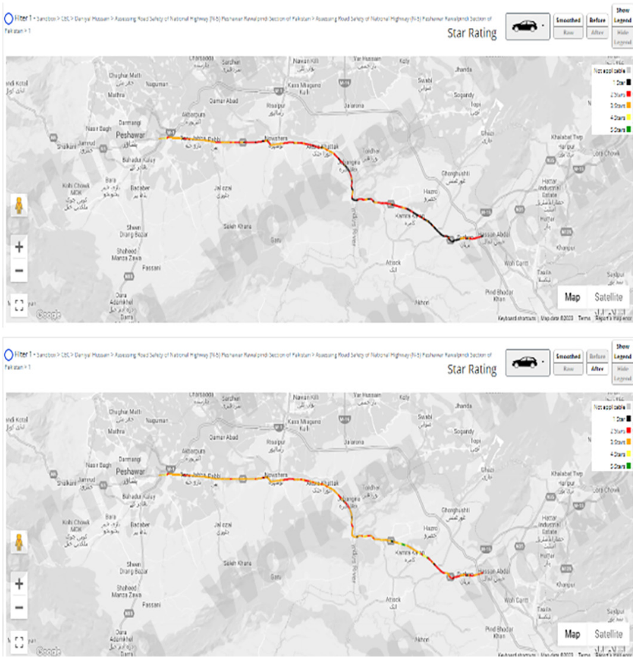


Fig. 9 Map of star rating before and after (smoothed)

implementation of countermeasures, this is done using a smoothed rating method.

3.2 Star rating table

The analysis also includes star rating tables, this is shown in Table 2, a display of safety assessments for the countermeasures before and after their implementation.

3.3 Star rating chart

Star rating presents the safety ratings for the countermeasures before and after their implementation in the smoothing process as shown in Fig. 10.

3.4 Star rating result's discussion

In Figs. 11 and 12, a comparison of the road's lengths and star ratings for the N-5 is done during the analysis. This highlights the important situation of road safety before and after the implementation of countermeasures. Before these countermeasures, N-5 posed a substantial amount of challenges to road safety. Many of the road segments received ratings from two stars to one star, indicating that it was not particularly safe for users of the road. All users of the road experienced substantial hazardous road conditions with little to no safety measures in place.

Fig. 10 Chart of star rating before and after (smoothed)

Among different vehicle users, 2-star conditions were substantial, covering 41.51% of the road length. The motorcyclists especially faced hazardous conditions, with 43.58% of the road being rated at 2 stars. Bicyclists and pedestrians face even more insecure conditions, as long portions of the road lack adequate safety countermeasures. However, after the safety countermeasures were implemented, the length of road segments with 3-star ratings have substantially increased, indicating

Table 2 Table of star rating before and after results (smoothed)

Star Ratings Table Result-Before								
Star Rating	Vehicle occupant		Motorcyclist		Pedestrian		Bicyclist	
	Km	%	KM	%	Km	%	Km	%
3 star or better	36.5	34.44%	16.3	15.38%	0	0.00%	29.4	27.74%
5 Stars	0	0.00%	0	0.00%	0	0.00%	0	0.00%
4 Stars	1.5	1.42%	0	0.00%	0	0.00%	0	0.00%
3 Stars	35	33.02%	16.3	15.38%	0	0.00%	29.4	27.74%
2 Stars	44	41.51%	46.2	43.58%	63	59.43%	41	38.68%
1 Star	25.5	24.06%	43.5	41.04%	43	40.57%	35.6	33.58%
Not applicable	0	0.00%	0	0.00%	0	0.00%	0	0.00%
Totals	106	100.00%	106	100.00%	106	100.00%	106	100.00%
Star Ratings Table Result-After								
Star Rating	Vehicle occupant		Motorcyclist		Pedestrian		Bicyclist	
	Km	%	Km	%	Km	%	Km	%
3 star or better	76.6	72.27%	48.1	45.38%	2.8	2.64%	56.9	53.68%
5 Stars	1.5	1.42%	0	0.00%	0	0.00%	0	0.00%
4 Stars	6.7	6.32%	0.6	0.57%	0	0.00%	0	0.00%
3 Stars	68.4	64.53%	47.5	44.81%	2.8	2.64%	56.9	53.68%
2 Stars	25.9	24.43%	48	45.28%	91.5	86.32%	39.6	37.36%
1 Star	3.5	3.30%	9.9	9.34%	11.7	11.04%	9.5	8.96%
Not applicable	0	0.00%	0	0.00%	0	0.00%	0	0.00%
Totals	106	100.00%	106	100.00%	106	100.00%	106	100.00%

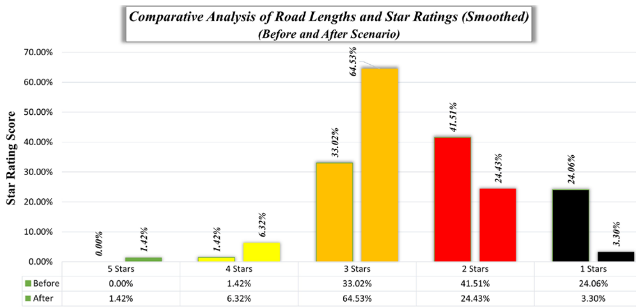


Fig. 11 Comparative analysis of road lengths and star ratings (smoothed)

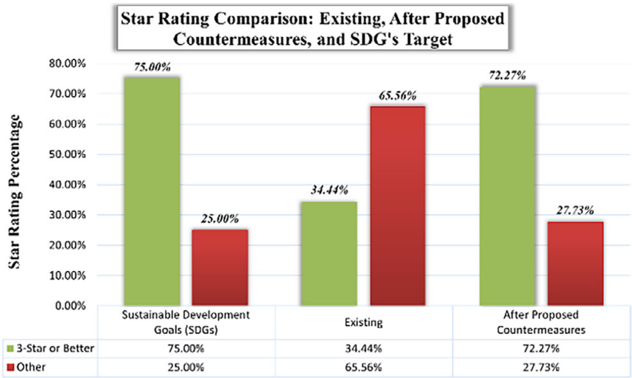


Fig. 12 Star rating comparison: existing, after proposed countermeasures and Sustainable Development Goal's star rating target

improved safety conditions for all the road user categories. The pedestrian and bicyclist safety showed a great improvement, underscoring the positive impact of these interventions. Amongst the different vehicle occupants, the 3-star conditions become considerable, covering about 64.53% of the length of the road. Motorcyclists also experienced improved conditions, with 44.81% of the road now being rated at 3 stars.

Figs. 12 and 13, highlights the significance of implementation of countermeasures. It is amply clear that the implementation of geometric safety countermeasures has improved the road safety of N-5. These results show a significant rise in the overall percentage of road segments that now receive a 3-star rating or better. Prior to the

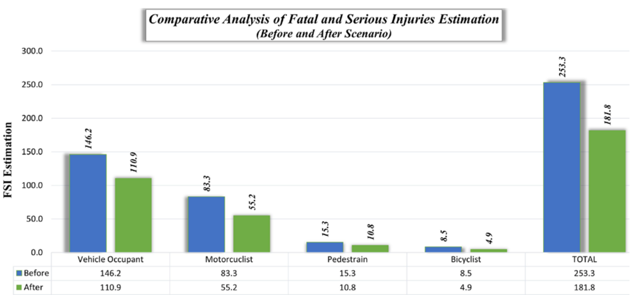


Fig. 13 Comparative analysis of fatal and serious injuries estimation

changes, only a total of 34.44% of segments received a rating of 3 stars or higher, whereas after the changes, safety exceeded 72.27%. The Road safety analysis showed that, with the application of geometric safety countermeasures, the overall safety rating was susceptible for the road users. To achieve 75% of the star rating set by UN, and to reach 75% of the star rating, hence it is important to recognize that the geometric safety measures have proven to be affective.

3.5 Safety Rating Investment Program (SRIP) result's discussion

According to Table 3, the table referred towards the investment plan details needed for the geometric countermeasures and implementations on the N-5 section, the number of crashes will be reduced, after the implementation of geometric countermeasures on N-5. The details such as benefit to cost ratio, fatal and serious injuries, and safety rating improvement program analysis were identified, along with length and section, where those implementations need to be implemented. The safety rating improvement programs (SRIP) result states that, due to the implementation of strategies, the fatal and serious injuries were reduced by 1,355 persons and Present Value (PV) of benefits was calculated as PKR 6,908,767,720 while the cost of implementation was estimated by PKR 1,436,026,941. Cost effectiveness could be reduced by approximately PKR 1,060,103 per person, the overall BCR ratio was calculated at 5, which shows that SRIP provides five times higher benefits. The result further explained that median crossing upgrade and sight distance, refer towards obstruction removals, demonstrate particularly high BCRs of 83 and 21. Countermeasures such as delineation and signing (intersection) shows a BCR vale of 1.

3.6 Discussion of FSI estimation results

Before the countermeasures were implemented, N-5 faced a substantial risk of fatal and serious injuries. The overall count of these injuries was 253 annually, which drastically affects the vehicle occupants, pedestrians, motorcyclists, and bicyclists. The occupants of vehicles had the highest number of injuries. After the implementation of safety measures, a remarkable improvement was seen, the number of fatal injuries reduced to 181 annually. The overall reduction represents a substantial improvement in road safety, although vehicle occupants still had the highest injury count. These findings highlight the positive impact of countermeasures on N-5, reducing the risk of severe injuries.

Table 3 Star Rating Investment Plan (SRIP)

Summary of Safety Benefits and Costs						
Total FSIs Saved	Total PV of Safety Benefit (Rs.)	Estimated Cost (Rs.)	Cost per FSI Saved (Rs.)		Program BCR	
1,355	6,908,767,720	1,436,026,941	1,060,103		5	
Countermeasure-Specific Details						
Countermeasure	Length / Sites	FSIs Saved	PV of Safety Benefit (Rs.)	Estimated Cost (Rs.)	Cost per FSI Saved (Rs.)	Program BCR
Bicycle Lane (on-road)	0.30 km	0.2	905,918	57,120	321,577	16
Delineation and Signing (Intersection)	54 sites	236	1,203,754,651	894,988,967	3,791,978	1
Improve Curve Delineation	22.40 km	208	1,058,742,514	57,714,181	278,021	18
Improve Delineation	77.50 km	127	649,928,664	97,165,971	762,491	7
Median Crossing Upgrade	32 sites	329	1,680,333,397	20,285,924	61,572	83
Refuge Island	16 sites	1	5,138,483	5,118,185	5,080,041	1
Roadside Barriers – Driver Side	8.90 km	47	241,828,903	79,108,694	1,668,408	3
Roadside Barriers – Passenger Side	20.60 km	69	351,325,462	20,084,958	291,573	17
Shoulder Sealing Driver Side (<1m)	1.50 km	3	16,485,891	4,467,188	1,382,000	4
Shoulder Sealing Driver Side (>1m)	36.80 km	58	295,498,156	119,516,731	2,062,814	2
Shoulder Sealing Passenger Side (<1m)	3.80 km	3	17,099,861	4,194,775	1,251,129	4
Shoulder Sealing Passenger Side (>1m)	47.60 km	45	228,771,252	45,995,625	1,025,419	5
Sight Distance (Obstruction Removal)	17.40 km	217	1,107,041,795	51,762,500	238,472	21
Unsignalized Raised Crossing	93 sites	10	51,912,774	35,566,123	3,494,205	1
		1355	**6,908,767,720**	**1,436,026,941**	**1,060,103**	**5**

As shown in Fig. 14, the plan to reduce the causality along the selected corridor, the result and analysis shows that most of the area have serious fatal injuries per kilometer.

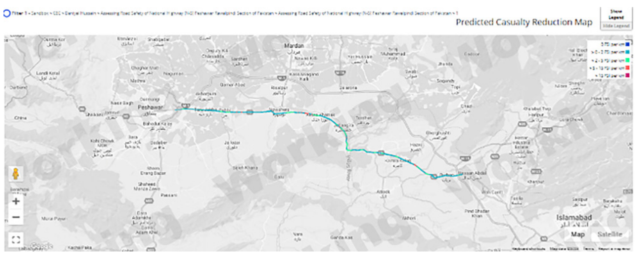


Fig. 14 Predicted causality reduction map

4 Conclusions

The implementation of geometric safety measures on road N-5 has significantly improved road safety.

These interventions have resulted in better safety ratings, particularly benefiting vulnerable road users, and have led to a noticeable decrease in Fatal and Serious Injuries (FSIs), with an impressive Benefit-Cost Ratio (BCR) of 5. Despite the effectiveness of these measures, the United Nations' Sustainable Development Goal of achieving a 75% Star Rating of 3 stars or better has not been fully achieved. To enhance road safety comprehensively, it is essential to adopt a more holistic strategy, i.e., traffic control devices, traffic signage plans, traffic islands, pavement maintenance and rehabilitation, and road markings, along with other non-geometric strategies, such as clearing roadside hazards, one-way networks, and enhancing street lighting. When used alongside geometric interventions, these additional measures can help create a safer road environment, further reducing the possibility of accidents and injuries.

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