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The Impact of Low-Cost Black Spot Treatment: A Case Study of a Multi-Level Bridge in Karachi, Pakistan

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ABSTRACT: Treatment of high accident concentration areas plays a crucial role in safety improvement. This paper presents a detailed case study on data-driven identification, analysis, improvement, and benefit-cost evaluation of a selected black spot in Karachi, Pakistan. The black spots were identified based on the accident data collected from 2007 to 2015 at the Road Traffic Injury Research & Prevention Center (RTIRPC). Road safety audits and on-spot accident investigations were conducted to investigate the contributing factors. The black spot under consideration is a bridge passing over an interchange in the southern part of the city near the coastline. The proposed interventions were implemented with the help of funding from the private sector. The pre-treatment economic loss due to road traffic injuries, fatalities, and loss of work was calculated. The post-treatment benefits in terms of reduction in accidents and corresponding injuries and fatalities were estimated using RTIRPC data, and the benefit-cost ratio was examined. The post-treatment data showed a significant reduction in all types of accidents. It was concluded that low-cost treatments such as reduction in speed limit, provision of cat eyes, road signs, and transverse markings along with strengthening of safety barriers resulted in a benefit-cost ratio of 42.5.

KEYWORDS: Benefit-cost ratio; Black spot treatment; Horizontal curve; Injury prevention; Road traffic accidents

1. INTRODUCTION

Transportation through roads faces many challenges, with Road Traffic Accidents (RTA) being one of the most prominent adversities to faster mobility of goods and people around the globe. Road traffic accidents are among one of the leading causes of accidental deaths around the world. According to the World Health Organization, 1.35 million deaths were recorded in road crashes, and about 50 million people experienced nonfatal injuries in road crashes in 2018 (WHO, 2019). Road traffic accidents are considered as one of the human-induced disasters, which are increasing at a high rate and are multidimensional and complex.

A comprehensive accident database is essential to ascertain the burden of road accidents and improve road safety. For this purpose, the Road Traffic Injury Research & Prevention Centre (RTIRPC) was established in 2006 in collaboration with Jinnah Postgraduate Medical Center (JPMC), NED University of Engineering and Technology, and Aga Khan University (AKU) Hospital with funding from Indus Motors (Pvt) Limited. The RTIRPC was closed in 2017 due to lack of funding. During its existence, RTIRPC performed an extensive analysis of road accident data, advocated various policy measures to improve road safety, published various research papers (Ali & Ahmed, 2009; Jooma & Shaikh, 2016, 2017; Kazmi & Zubair, 2014; Khan, et al., 2015; Lateef, 2011; Mehmood, et al., 2013; Razzak, et al., 2011; Razzak, et al., 2012; Shamim, et al., 2011; Zubair, et al., 2015; Zubair & Kazmi, 2013), and conducted numerous accident investigations and black spot analyses. RTIRPC was mainly funded for data collection and analysis, with no funding for directly implementing any of the intervention strategies or black spot improvement. Jinnah Interchange was the only major black spot treated by the team of RTIRPC with funding from a private organization after acquiring appropriate approvals from the administrative authorities. The local authorities implemented various other improvement measures as a result of the policy measures recommended by RTIRPC. However, detailed data on those interventions are not available. Therefore, this is the first research on a case study of data-driven black spot treatment from a megacity. This research uses the injuries and fatalities data collected by RTIRPC along with the loss incurred due to accidents, including the cost of treatment, loss of work, and damage to the vehicles due to the accident as reported in the existing literature, to estimate the economic loss due to accidents at Jinnah Interchange. The economic loss presented in this research does not include the cost of loss of life in a fatal accident due to a lack of available data. Furthermore, Property Damage Only (PDO) accidents are also not included in the pre-and post-analysis of economic loss, as these accidents are not reported to hospital emergencies and, hence, not recorded by RTIRPC.

2. LITERATURE REVIEW

An accident is an outcome of the interaction of various traffic system components which include road users, road environment, and vehicles (Bulatov, 2022). The discontinuities in road design and abrupt changes in the road environment affect the drivers' comprehension, which may lead to wrong and abrupt maneuvers. Studies revealed that accidents are the consequence of a driver's behavior that is not correctly matched with the demands of the road environment, mainly where discontinuities in road design, vehicle characteristics, or both exist (Geurts & Wets, 2003). Numerous studies have confirmed that accidents usually occur because of the driver's attitude and vehicle condition. Road environment or climate variables, i.e., average temperature and standard precipitation, also affect road traffic safety (Zou, et al., 2021). Studies conducted on road safety revealed that there is a non-linear relationship between crash frequency and hourly traffic volume (Hesjevoll & Elvik, 2016). Wanger, et al., (2021) analyzed several databases and concluded that the crash frequency saturates with larger traffic flow. The presence of young and novice drivers is over-represented in crashes (European Commission, 2021). Therefore, it is the responsibility of municipal authorities to maintain the road environment in such a manner that an equilibrium exists between driving demand and driver's capabilities (Oxley, et al., 2004).

Road crashes occur in some segments with higher frequency than the other segments, which are usually known as 'black spots'. According to Hauer (1996), black spots can be prioritized based on either accident rates (accidents per vehicle-kilometers or per entering vehicles), accident frequency (accidents per km-year or accidents per year) or a combination of the two techniques. It is vital to identify RTA locations and clusters (black spots), as well as their major causes and remedies to improve road safety. The Highway Safety Manual (HSM) (National Research Council, 2010) recommends network screening techniques for the identification and prioritization of black spots. PIARC Road Safety Manual also recommends the network-level approach for the identification of high-risk locations. Various other methods to identify black spots with even small accident numbers have been developed (Anderson, 2009; Driss, et. al., 2011; Jayan & Ganeshkumar, 2010; Oppe, 1982). The analysis of these clusters as black spots can assist in disaster preparedness, and loss prevention (Driss, et al., 2011). The locations where road accidents are expected to occur more frequently, and losses are higher are classified as risky areas.

Four major techniques for reducing crashes have been proposed by applying engineering interventions (Meuleners, et al., 2008). These techniques are listed below:

- Single sites or black spots treatment;
- Route action;
- Area-wide action; and
- Mass action.

General knowledge of road safety is essential but insufficient when dealing with specific problems of the area being treated. It must be complemented by the results of the analysis of accident data in the area being corrected. Black spot treatment improves road safety through the improvement in the road geometry and environment of the selected site. Vistisen (2002) divides the black spot treatment procedure into three steps:

1. Identifying black spots.
2. Prioritizing the black spots for treatment.
3. Pre and post-studies of the implemented treatment.

A significant number of overall road crashes can be reduced by treating the major black spots in a road network. Nguyen, et al. (2013) applied a network safety approach and identified black spots in Ho Chi Minh City, based on the safety potential approach. Ahmed, et al. (2019) identified the causes of errors in recording and reporting accident data, which may lead to inaccurate location identification and black spot analysis. Another study conducted in Hungry proposed a block spot identification algorithm based on the data mining approach, which utilizes the GPS data of accident locations (Szénási & Jankó, 2016). Thus, the accuracy of accident data plays a critical role in the identification and treatment of black spots.

Two available approaches to improve the road safety of commuters in a road network include reactive (black spot treatment) and proactive (road rating) approaches. Job (2012) evaluated the advantages and disadvantages of black spot treatment and road rating approaches. He concluded that the black spot treatment approach is more appropriate if the data on road crashes is available, and the other approach is more useful when extensive and accurate data does not exist. Meuleners, et al. (2008) studied the effectiveness of the black spot treatment program in Western Australia. The study concluded that black spot treatment program resulted in a 15% reduction in overall road crashes, while the estimated crash cost savings was 50.8 million Australian dollars with a benefit-cost ratio of 4.9. De Pauw, et al. (2014) evaluated the effectiveness of black spot treatment project in Flanders-Belgium. The study evaluated the pre and post-treatment data of 134 black spots and recorded a 24-27% reduction in minor injury crashes and a 46-57% reduction in crashes resulting in severe or fatal injuries.

The socioeconomic benefits of black spot treatment can be estimated by reducing accidents and resulting injuries and fatalities. An injury results in the following losses (Al-Masaeid, et al., 1999; Manouchehrifar, et al., 2014; Razzak, et al., 2011):

1. Cost of medical treatment to cure injury;
2. Loss of work due to the time taken to recover from injury;
3. Cost to repair the vehicle(s) damaged in an accident;
4. The psychological impact of the accident on the victim and his/ her family.

Repairing black spots results in fewer accidents and injuries, saving the costs mentioned above. The cost of recovery from injury, loss of work, and vehicle repair changes from country to country. Furthermore, it also depends on the severity of the injury, vehicle type, and socioeconomic background of the victim. Loss of work cost is significantly dependent on the age and status of the victim (breadwinner or not)(Razzak, et al., 2011).

In road transportation, skid resistance or friction plays a vital role in providing control of the vehicle to the drivers. The coefficient of friction between the road and tyre ranges from approximately 0 (under icy conditions) to around 1.0 when both surfaces are in perfect condition (*Road safety manual*, 2003). The friction along the direction of vehicle movement is longitudinal, and the friction perpendicular to the movement of the vehicle is transverse friction, which provides skid resistance to the vehicle. The skid resistance of the road surface is an important parameter, especially under wet road surface conditions. The risk of an accident on pavement with a skid friction coefficient less than 0.45 is 20 times higher than the pavement with a coefficient greater than 0.6. For the coefficient of skid friction less than 0.3, the risk of an accident increases 300 times (Great Britain Highways Agency, 1994). Malin, et al. (2019) found that accident risks were increased for poor road weather conditions, and they were the highest for slippery and very slippery road conditions. Lambourn & Viner (2005) found that potentially dangerous driving conditions were caused due to low friction, poor road geometry or road contamination.

Road safety is a serious but ignored problem in Pakistan. Karachi is the economic hub and most populous city of Pakistan (World Population Review, 2024). This city has the highest number of road traffic accidents occurring in the country and the fourth-highest RTA fatalities in the world (Dawn, 2019). According to research, more than 30,000 road traffic injuries are reported in Karachi every year (Razzak, et al., 2012). The increment in trade activities in the city, increase in vehicular ownership, especially motorbikes (Amena & Baqueri, 2019), and lack of public transport have led to an increase in vehicular movement (Noman, et al., 2020), which, combined with poor maintenance of road infrastructure and lack of traffic law abidance, has resulted in an increasing frequency of accidents in Karachi. Moreover, signal-free corridors have also increased the risk of road accidents in Karachi (Zubair, et al., 2015). The increased number of accidents in Karachi indicates that road safety is a major problem, and hence improvements are needed to reduce traffic accidents. Black spot treatment, as identified in the literature cited above, could be a useful approach to treat the locations with high injury frequency and severity.

This paper presents a case study on back spot identification, investigation, and evaluation of the impact of intervention implementation from a megacity of a developing country. The paper is focused on highlighting the potential of reducing road accidents and resulting injuries and fatalities through low-cost black spot treatment methods. The economic loss due to injuries and fatalities and the benefit-cost ratio are estimated using the RTIRPC data. This research shows that there is an enormous potential for achieving safer roads through the treatment of such black spots.

3. METHODOLOGY

3.1. Data collection

This research is based on the road accident and injury data obtained from RTIRPC. This institution collected data from victims of road accidents reported to five major trauma centers in Karachi, which included Jinnah Postgraduate Medical Centre, Civil Hospital Karachi, Abbasi Shaheed Hospital, Liaquat National Hospital, and Aga Khan University Hospital. The data was collected for a period of nine years from 2007 to 2015, using a dedicated team of 25 data enumerators. The data was collected every day throughout the year from all the victims of road accidents reported to the selected hospitals. The data was collected using a questionnaire which included details about the victim; time, location, and cause of the accident; type of vehicles; types of collision; and information on the victim's injury.

Black spots were identified and prioritized based on the road traffic injury data using the framework described in the HSM. HSM recommends screening the network for the identification of black spots. The accident severity index for all the listed black spots was computed, and Jinnah Interchange was found among one of the top 10 black spots. The main causes of accidents were identified through the injury data. Road safety audits were conducted to examine the existing problems at the identified black spot. Accident investigations were also carried out to investigate some of the accidents resulting in fatal and serious injuries. The on-site accident investigations helped identify the causes of accidents. The analysis of the black spot presented in the following section is based on the findings of accident investigations and road safety audits conducted on-site.

This research paper presents the evaluation of the treatment of a selected black spot, which was treated based on the evaluation report prepared by the authors at RTIRPC. The impact of black spot treatment was evaluated by comparing the number of road traffic injuries and fatalities before the treatment with the number of injuries and fatalities after the treatment. Figure 1 shows the methodology of the framework applied in this research.

3.2. Benefit-Cost analysis

The benefit-cost ratio is a common analysis method applied in almost every improvement project to evaluate the economic benefits of the project. It helps identify whether the project is economically feasible by providing a simple ratio. If the ratio is greater than one, the project is considered beneficial, and vice-versa. In the context of this study, the potential benefits in terms of reduction in the treatment cost of patients with minor or severe injuries, reduction in the cost due to loss of work, and reduction in vehicle damage cost were estimated. They were divided with the overall cost of the various kin ds of interventions made at the site, to obtain the benefit-cost ratio. This relationship is explained in Equation 1.

$$\text{Benefit} - \text{Cost Ratio} = \frac{\text{Benefit in terms of reduction in injury treatment cost} + \text{loss of work cost} + \text{vehicle damage cost}}{\text{Cost of signs and markings}} \quad (1)$$

4. ANALYSIS AND EVALUATION OF BLACK SPOT TREATMENT

Jinnah Interchange was on one of the top 10 black spots identified and treated by RTIRPC. Jinnah interchange is located between Kharadar and Kemari on China Creek in Karachi. This interchange connects Karachi port to the city and it is an important segment of one of the principal arterials of Karachi, namely M. A. Jinnah Road. Jinnah interchange consists of an elevated four-leg roundabout (at the first level) with another elevated ramp connecting MT Khan Road with Mauripur Road (at the second level), while railway lines and freight-related activities are carried out at ground level. Figure 2 shows the satellite image of the interchange taken from Google Earth. The traffic at the interchange can be characterized as mixed traffic which includes heavy trailers, dumpers, public transport, cars, and motorbikes. The elevated ramp is reserved only for cars, motorbikes and small commercial vehicles. The entry to the ramp is controlled by height clearance bars, as no trucks and heavy vehicles are allowed on this elevated ramp.

Fig. 2. Google Earth Imagery of Jinnah Interchange

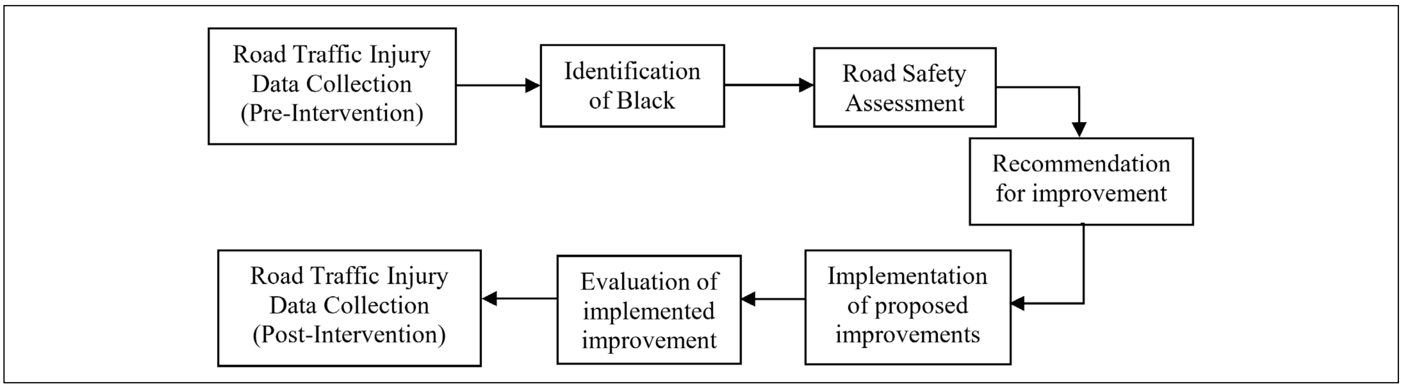


Fig. 1. The framework of Road Safety Assessment and Improvement of black spot locations

Fig. 3. The curve on the elevated ramp without safety signs

The RTIRPC data for the Jinnah interchange reveals that most of the incidents at this interchange are reported from the elevated ramp. Several site visits were arranged in August 2007 to investigate this black spot. Black spot investigation and analysis of data for this spot revealed that most of the accidents were reported with vehicles skidding at the curve of the elevated ramp. The ramp is a two-way and two-lane carriageway with one lane in each direction. The width of the lane is 10 feet with a 9-inch wide and 4-inch high tapered median provided between the lanes carrying traffic in the opposite direction. Figure 3 shows the picture of the carriageway taken as part of the investigation. The factors that contributed to accidents identified during the investigation of this black spot have been discussed in the subsequent sections.

4.1. Horizontal curvature

There are two horizontal curves on the elevated ramp, which are identified as the black spot on the Jinnah interchange. The sharper of the two curves has an estimated radius of 109 meters and a degree of curvature equivalent to 16 degrees while the other curve has an estimated radius of 435 meters and a degree of curvature equivalent to 4 degrees. This sharp curve on the narrow dual carriageway with a very small median without any safety devices was identified as a contributing factor in roadway departure collisions on this ramp. Vehicles traversing the curve at high speed increase the risk of roadway departure and/ or head-on collision. This problem becomes more critical for motorbike riders as the tapered median provided with a height of 4 inches is too small to deter a vehicle. The vehicle directed outward from the lane may collide with the vehicles coming from the opposite direction.

4.2. No speed limit signs

It was also observed that due to low traffic volume on the elevated ramp, the vehicles travel on the ramp at higher speeds. The average observed speed of vehicles during two hours was 41 km/hr along the curves with a standard deviation of 3.5 km/hr. However, like other roads in Karachi, no speed limit sign was observed on the ramp. The speed limit on the ramp should have been defined, especially on curves to improve the safety of commuters on this ramp.

4.3. No road sings

During the black spot investigation, it was observed that no warning signs on the approaches of the curve were installed to inform the drivers about the approaching hazard (curve). Furthermore, roadside delineators, which are necessary to inform the driver about the existence and direction of curvature, were also observed to be missing.

4.4. Low skid resistance

The RTIRPC data and black spot investigation revealed that there is a problem of skid resistance as well on the elevated ramp under investigation. A fatal accident caused due to skidding off a car, which then fell off the ramp, was investigated on-site by the team of RTIRPC (Dawn, 2008). With the spot

(a) British Pendulum Tester. **(b) Auto-Level with Staff.**

Fig. 4. Measurement of skid resistance and superelevation at Jinnah Interchange.

located close to the coastline and seaport, the humidity is usually high in this proximity. Furthermore, leakage of fluid from vehicles loaded with fishery products passing through the interchange contributed to reducing the friction on the elevated ramp.

The skid resistance was measured by using the Skid Resistance Tester. The Skid Resistant Tester consists of a pendulum with a piece of rubber, which is attached to a needle. When the piece of rubber attached to the pendulum hits the pavement surface, the resistance between the road surface and the rubber is recorded by the attached needle as the Skid Resistance Number (SRN). The skid resistance number measured on Jinnah Interchange was compared with a newly constructed road in Karachi at that time with better surface quality, namely Abul-Hasan Isphahani Road. The value of the skid resistance number on the surface of the newly constructed road was taken as a benchmark. The test was carried out on Abul-Hasan Isphahani Road in front of NED University Colony Gate. On Jinnah Interchange, the test was carried out at the turning of the curve. The tests were performed in dry and wet conditions. Water was sprinkled on the road surface to determine the SRN in wet conditions.

The SRN measured at the Jinnah Interchange depicts the problem of lower skid resistance, especially at the curve of the ramp. The observed value of SRN at the elevated ramp is 18.18% lower than the value observed at Abul-Hasan Isphahani Road. Under the wet conditions, the skid resistance number on the ramp of Jinnah Interchange decreased from 45 to 30, which shows a reduction of 33% in skid resistance under wet conditions. This indicates that skid resistance is also one of the causes contributing to accidents on this spot. The values of field measured SRN are shown in Table 1 and the pictures taken during measurements are shown in Figure 4.

Location	SRN under Dry Condition	SRN under Wet Condition
Abul-Hasan Isphahani Road	55	44
Jinnah Interchange (Elevated Ramp)	45	30

Table 1. SRN under dry and wet conditions at two different locations.

4.5. Superelevation

Superelevation is one of the critical design elements, which governs the design speed and turning radius. On Jinnah Interchange, superelevation was measured using Auto-Level. The difference in elevation between the outer and inner edge of the pavement provided the value for the superelevation at the given location. The measurements were taken on the upper ramp of Jinnah Bridge at two points where the curve is sharpest. The results of this exercise are shown in Table 2.

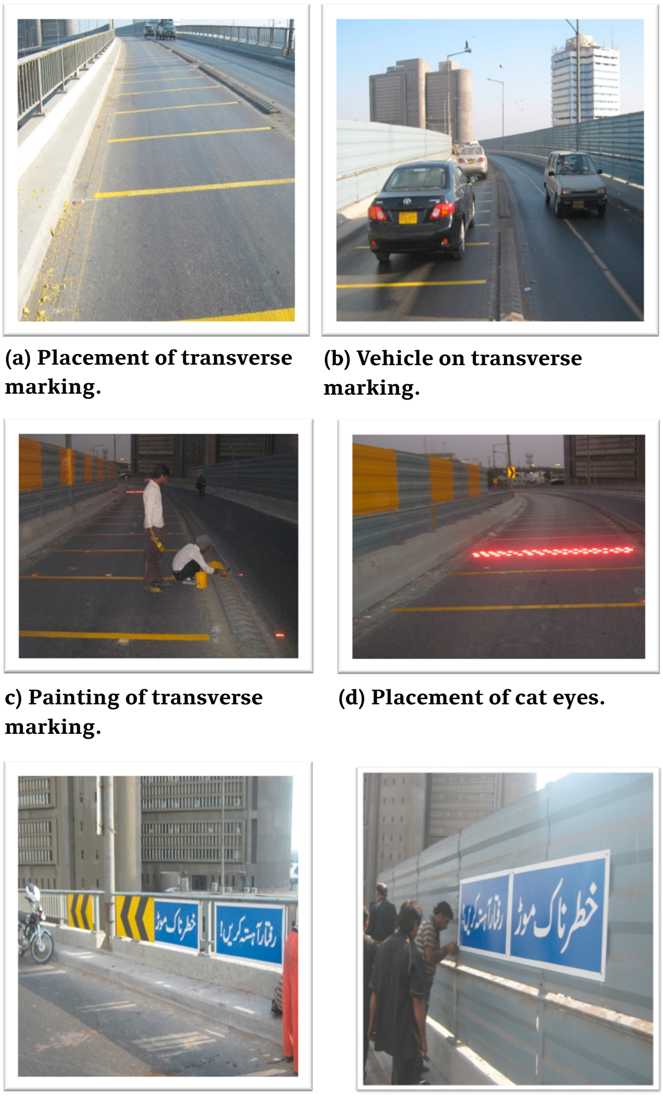
Station	Superelevation on the ramp leading from MT Khan Rd to ICI Bridge	Superelevation on the ramp leading from ICI Bridge to MT Khan Rd
Curve - 1	2%	2%
Curve - 2	5.4%	3.9%

Table 2. Superelevation on the elevated ramp of Jinnah Interchange.

4.6. Intervention measures

The radius of the curve measured from image processing was found to be 231 m. According to the AASHTO manual (Leisch, 2005), the design speed for the given radius and superelevation is 40km/hr. By keeping a factor of safety, a safe speed of 35km/hr could be suggested as the speed limit at the ramp/curve.

The calculated safe speed at the curve was estimated to be 40 km/hr, whereas the measured average speed of vehicles on the segment of the curve was 41 km/hr. This indicates that there is a need for reducing the speed of vehicles on the ramp, especially along the curve to reduce the number of accidents on the ramp.



(a) Placement of transverse marking. **(b) Vehicle on transverse marking.**
c) Painting of transverse marking. **(d) Placement of cat eyes.**
(e) Traffic sign with delineator. **(f) Traffic warning sign.**

Fig. 5. Implementation of the proposed improvements on the Jinnah Interchange.

Based on the findings of the investigation, the following black spot treatments were forwarded to the concerned authority (City District Government Karachi (CDGK), Karachi Port Trust (KPT), and were implemented in January 2012 with the support of funding from a sponsor.

- Provision of transverse bars and cat eyes at the curve to improve friction and reduce travel speed.
- Provision of proper turning signs and the speed limit on the curve of the ramp to inform commuters about speed reduction.
- Strengthening the barrier of the ramp at the curves to stop the falling-off of vehicles from the ramp.

The proposed interventions changed the road environment, especially at the curve on the upper ramp of the interchange. Figures 3 and 4 show the pre-treatment picture of the curved ramp, and post-treatment pictures are shown in Figure 5. The proposed interventions improved the road environment at the curve of the ramp, which was expected to reduce the number of fatalities and injuries reported in road traffic accidents at this interchange. Table 3 compares the annual number of fatalities and injuries for eight years, which shows a significant improvement in the number of fatalities and injuries after the proposed interventions were implemented in January 2012. The number of fatalities dropped from 13 in 2007 to 4 in 2012. The number of serious injuries dropped from 29 to 2, whereas the number of minor injuries dropped from 91 in 2007 to 9 in 2012.

Injury Severity	2007	2008	2009	2010	2011	2012	2013	2014
Minor	91	116	101	46	112	9	24	16
Serious	29	26	17	15	21	2	5	5
Fatal	13	13	5	10	9	4	1	1

Table 3. Annual distribution of Injuries by Severity (2007-2014).

5. BENEFIT-COST ANALYSIS OF BLACK SPOT TREATMENT

5.1. Cost of Black Spot Treatment

The statistics of accident data and the findings of road safety audits were shared with the relevant authorities and organizations on various platforms. Finally, representatives from the Karachi Chamber of Commerce and Industry agreed to finance the black spot treatment identified at Jinnah Bridge. The field team aimed to perform the task with minimum cost. The reflectors and cat eyes were donated by the 3M. The total expenditure of carrying out the proposed improvement was around USD 3,000, including the cost of reflectors obtained from 3M.

5.2. Benefits of Black Spot Treatment

This research uses the values of losses incurred due to accidents reported in the existing literature for Karachi and Pakistan. Razzak, et al., (2011) estimated the cost of injury treatment and loss of work for minor and severe injuries, as well as the treatment cost of a victim suffering fatal injuries. The total number of injuries in the above-mentioned categories was multiplied by their respective costs to determine the total treatment and loss of work cost. Razzak, et al., (2011) collected data on the cost incurred to cure the injury and the loss of work from 500 randomly selected victims or their relatives using a telephone-based survey technique. The participants were selected from the RTIRPC data, which included representation from all age groups, injury severity, type of vehicle, and socioeconomic background. However, Razzak, et al., (2011) did not provide an estimate of loss due to the death of a victim, and there is no study available from Pakistan in this context. Therefore, this element of loss due to accidents is not included in economic loss in the pre- and post-treatment scenario of the selected blackspot.

The estimated loss due to vehicle damage is based on a study conducted in Lahore, Pakistan, which is a metropolitan city with dynamics similar to Karachi (Ali, et al., 2018). They estimated the average repair cost of the vehicle after getting damaged in various types of accidents, including property damage only, minor, serious, and fatal accidents (Ali, et al., 2018). The estimation of vehicle damage loss was based on the total number of vehicles involved in different types of accidents.

The estimated costs of accidents at the selected black spot of Jinnah Interchange are shown in Table 4, which indicates a significant decrease in the cost of accidents. The highest total cost of accidents was estimated for the year 2007. The least loss due to accidents was observed for the year 2012 when it dropped from USD 65,042 to USD 9,423. Table 4 shows that the average annual cost of accidents on this black spot before treatment was USD 52,371, which was reduced by more than fivefold to USD 9,790 after the treatment.

	Year	Treatment Cost (USD)	Loss of Work Cost (USD)	Vehicle Damage Cost (USD)	Total Cost (USD)	Average Cost (USD)
Pre Treatment	2007	25160	6276	33606	65042	52371
	2008	25054	6277	33645	64976	
	2009	17020	4580	19157	40756	
	2010	13814	3226	21278	38318	
	2011	20978	5416	26371	52764	
Post Treatment	2012	2726	484	6213	9423	9790
	2013	4526	1239	4753	10518	
	2014	4029	1088	4313	9430	

Table 4. The economic cost of accidents at Jinnah Interchange.

The economic benefit of reducing the number of accidents for three years can be estimated by the sum of the difference in economic loss for a given year after the treatment compared to the average loss before the treatment. Therefore, the benefit-cost ratio of the treatment of this black spot can be estimated as follows:

$$Benefit-cost\ ratio=\frac{Estimated\ benefit}{Cost\ of\ treatment}=\frac{(52371-9423)+(52371-10518)+(52371-9430)}{3000}=42.5$$

6. DISCUSSION

This research presents the improvement in road safety achieved through various low-cost improvement measures. The overall reduction in accidents and the estimated benefit-cost ratio show a combined impact of all the improvements, and quantifying the impact of each measure would be a complicated task. Therefore, the identification of the most effective or least effective measures out of the applied solution is not currently included in the scope of this paper. Yannis, et al. (2016) listed most of the possible safety interventions and classified the interventions based on their costs and effectiveness. Table 5 lists the intervention measures along with their classification in terms of cost and effectiveness, as presented in Yannis, et al., (2016). The effectiveness of the measures is also compared with the benefit-cost ratio of various interventions reported by Daniels, et al. (2019).

Intervention	Cost (Yannis et al., 2016)	Impact (Yannis et al., 2016)	Cost-effective (Daniels et al. (2019)
Pavement markings	Low	Low	-
Traffic calming (Cat Eyes)	Low	High	18.2
Reduction in speed limit	Low	High	2.1
Road signs at curves	Low	High	2.7
Road barriers	Low	High	19.5

Table 5. Comparison of cost-effectiveness of various low cost road safety interventions

The transverse pavement markings alter the driver and increase road friction on the curve. This intervention is listed as a low-cost solution with a low impact on improving road safety. Traffic calming, such as installing cat eyes, is a low-cost and high-impact intervention. The best estimate of the benefit-cost ratio for this intervention is 18.2. Similarly, reductions in speed limits, the provision of road signs at the curve, and improvements in road safety barriers are also ranked as low-cost and high-impact measures. Out of these measures, the improvement of road safety barriers has the highest benefit-cost ratio of 19.5, whereas the reduction in speed limit has the lowest benefit-cost ratio of 2.1. This highlights that the interventions applied in this research are cost-effective in reducing the number of accidents and improving road safety. Interestingly, the sum of the benefit-cost ratio of all the interventions reported in Table 5 is 42.5, which is exactly equal to the benefit-cost ratio of improvement in Jinnah Interchange, as all these interventions were implemented on the same black spot. This also justifies the results of this research.

7. CONCLUSIONS AND RECOMMENDATIONS

This research paper presents a detailed case study on data-driven identification, analysis, improvement, and benefit-cost analysis of a selected black spot treatment from Karachi. RTIRPC collected data on accident victims reported to five major trauma centers in Karachi from 2007 to 2015. The RTIRPC data was used to identify the black spots and major causes of the accidents on those black spots. Road safety audits and on-spot accident investigations were also carried out to investigate the problems so that the appropriate interventions could be recommended to the relevant authorities and stakeholders for implementation.

Jinnah Interchange was investigated in detail, and the proposed improvements were implemented by RTIRPC with the help of a donation from the private sector. The data shows a significant reduction in the number of traffic accidents after the proposed improvements were implemented. Based on the estimated benefits achieved within three years of the treatment, the benefit-cost ratio of the black spot treatment was estimated to be 42.5.

The accident and injury cost estimation were based on the accident data collected at RTIRPC and previously published work on the cost of vehicle damage, cost of injury, and loss of work due to the accident. The economic cost estimated for each year did not include the cost incurred due to property damage only (PDO) accidents, as these types of accidents are not reported to any hospital and hence are not recorded by RTIRPC. Similarly, costs associated with road accident fatalities (loss of life) were excluded, which may have led to an underestimation of the benefits of black spot treatments. Additionally, the benefit-cost ratio was calculated using a simplified methodology that did not address complexities such as adjustments for regression-to-the-mean bias, potentially limiting the accuracy of treatment evaluation. Another important cost, often overlooked in existing literature, is the psychological impact on the victim. The reliance on hospital data poses its own limitations, as such records may have gaps when compared to actual incidents, potentially affecting the comprehensiveness of the economic analysis. Addressing these gaps in future studies could yield a more accurate and holistic understanding of the economic impacts of road accidents and interventions.

This research also highlights the lack of road markings and appropriate road furniture required to make the roads safer for commuters. The significant reduction in accidents at Jinnah Interchange was mainly achieved by improving the road environment needed for that section of Jinnah Interchange. It is also observed in Pakistan and other developing countries that road users are not appropriately made aware of changes in road conditions, especially on urban roads, which ultimately affects their driving behaviour in those locations. Therefore, it is recommended that existing roads should be evaluated in detail for lack of road furniture and should be upgraded with the necessary road furniture.

This research shows that black spot treatments have tremendous potential to reduce accidents and improve road safety for commuters. Data-driven black spot identification and treatment ensures that the cost of treatment will yield much higher benefits. The improvement in the number of injuries and fatalities with the help of the private sector highlights that municipal authorities should include the improvement of black spots in their improvement plan, which could significantly reduce the number of accidents.

The accident data collected with details of the location and cause of the incident is extremely useful in improving the road safety of commuters. However, due to lack of funding, RTIRPC could not sustain its vast operation of accident data collection after 2015 and ultimately closed its operations in 2017. In the absence of the data collected from the trauma centers, the potential of utilizing some alternative accident database, such as police data, should be explored to continue the process of black spot identification and treatment.

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