Mehran University Research Journal of Engineering and Technology

https://doi.org/10.22581/muet1982.2304.2893

2023, 42(4) 123-139

Discovering blackspots caused by pavement distresses using Lagrange polynomial and safety inspections of traffic accidents: A case study for Karachi, Pakistan

Khawaja Sheeraz [a, b, *], Naeem Aziz Memon [c], Aftab Hameed Memon [d], Nafees Ahmed Memon [c], Syed Faraz Jafri [a]

[a] *Department of Civil Engineering, Mehran University of Engineering and Technology, Jamshoro*

[b] *Sir Syed University of Engineering and Technology, Karachi, Pakistan*

[c] *Department of Civil Engineering, Mehran University of Engineering and Technology, Jamshoro, Pakistan*

[d] *Civil Engineering Department, Quaid-e-Awam University of Engineering, Sciences and Technology, Nawabshah, Pakistan*

[*] Corresponding author: Khawaja Sheeraz, Email: 19sphdghe01@students.muet.edu.pk

Received: 06 July 2023, Accepted: 25 September 2023, Published: 01 October 2023

KEYWORDS

Traffic

Accidents

Pavement

Distress

Lagrange

Safety

ABSTRACT

It is undeniable that as vehicle ownership increases; developing countries are constantly dealing with serious issue of traffic accidents. The pavement distress issue is reported as an elementary road entity causing accidents. According to the statistics of the Road Traffic Injury Research and Prevention Centre (RTIR&PC) in Karachi, more than 50% of serious injuries occur due to road faults. This paper aims to develop a mechanism for the exploration of blackspots by inspecting the traffic accidents in Karachi city caused by road distresses. The mathematical analysis involved the Lagrange polynomial method while the screening of blackspots was carried out based on safety inspections. As of lack of technicalities and improved documentation, the paper presented an initiative of complete guidelines for safety audits and investigations specifically for developing countries like Pakistan. According to findings, around 87% locations are pertained with the ranking of blackspots highlighting the pavement problems of the city.

1. Introduction

According to World Health Organization (WHO), road safety is a public health issue [1]. Usually, the problems of road safety are man-made hence its solutions could be with an emphasis on technical factors [2]. Several researchers have pointed out that, there is a directly proportional relationship between vehicular population and the rate of traffic accidents in the majority of developing countries [3]. Hence, the measures taken for each country are also dependent on the requirements of existing or vulnerable road user groups. It is quite evident that there are certain standards available for geometric or pavement design but unfortunately, there is a lack of standards for road users and mechanisms to encounter traffic accidents [4]. Like other cities of the world, Karachi is also facing the same problem where a huge number of accidents are reported. The situation of the city of Karachi, Pakistan is a thought-provoking situation that requires considerations to undertake the list of blackspots for future work by relevant stakeholders [5]. According to the data, in addition to other reasons for road accidents, pavement falsities are also a major cause of crashes. Pavement inadequacies are accounted with the inappropriate measures taken during respective construction. Besides that, it is also dependent on the rehabilitation measures proposed against pavement maintenance. Road users are the direct players on the road and in the same way, drivers are normally forced to malfunction their vehicles on dilapidated pavements [6]. In such circumstances, it is required to overlook the pavement conditions of the city providing the drivers comfort and smooth mobility on major arterials [7]. Table 1 shows the traffic crashes of different countries with respect to the road user groups in which the data of Karachi, Pakistan is introduced for basic understanding.

Table 1

Trends of traffic crashes in different countries w.r.t. road users categories [8]

Countries	Pedestrians	Riders	Four Wheelers	Others
Australia	18%	10%	65%	7%
Japan	28%	21%	41%	10%
Malaysia	15%	57%	18%	10%
Netherlands	10%	12%	56%	22%
Norway	15%	12%	65%	8%
Thailand	10%	73%	13%	4%
USA	12%	5%	80%	3%
Delhi, India	42%	28%	14%	16%
Bandung, Indonesia	33%	41%	17%	9%
Colombo, Sri Lanka	39%	35%	14%	12%
Karachi, Pakistan	48%	47%	4%	1%

Based on above table 1, a comparison of the ratios in the developed and developing countries shows that a large number of four-wheelers are involved in traffic crashes in developed countries whereas the scenario in developing countries is entirely different (high percentage of Riders and Pedestrians) [8]. It is necessary to focus on a specific strategy for the implementation of any road safety system which should resemble the solutions to targeted problems. Following the respective problems, technical measures are presented to provide safety facilitation to the specific road user group. Furthermore, the rate of accidents may differ depending on the finalized blackspots. When conducting a pavement or road safety study for a city, benchmark data is required for preliminary analysis [9]. As a result, the analysis is streamlined with some qualitative measures such as; physical audits [10]. It is obvious that such type of studies should follow a standard procedure for correct location screening. To provide a pavement construction solution, the system must be dependent on the suitability of mechanism proposed on actual grounds, while it should be represented based on detailed analysis and formal survey procedures which is the ultimate goal of this research study. The study is conducted based on qualitative and quantitative assessments of traffic accidents in Karachi holding physical inspections and detailed data findings. Detailed analysis is typically carried out using sophisticated mathematical tools. This research is validated using the Lagrange Polynomial technique and correlation measures to select a list of blackspots in terms of pavement distresses. In this regard, a separate mechanism is pronounced for identifying blackspots in traffic accident presenting road distresses. Considering the above factors, the gap in the research area may be easily dominated with the vision to explore and discover blackspots through formal techniques. Not only that, this area also needs to be strengthened for the practitioners so as to become the novelty of the stated research work.

2. Pavement Management System

Due to increased vehicle ownership trends, there is a rapid increase in traffic on the road. Each household has more than one vehicle for their daily use and similarly comes across a dense population of commuters on major routes [11]. This results in the low provision of mobility and numerous contributory factors, and there is a substantial increase in road crashes [12]. Ultimately, there is significant raise in the number of accidents. Studies show that it is very common to experience deteriorated roads malfunctioning for huge traffic volume [13]. This indicates an ineffective road maintenance and management system during the initial run [14]. Developing countries are attributed towards the low cost solutions for concerned cities to solve the issues of pavement management system [15]. Researchers are striving to find the sustainable solutions for practitioners and stakeholders in order to improve the road performance [16]. Unfortunately, the key players and relevant stakeholder groups are restricted with the usability of conventional approaches instead of creating the protocols and users guidelines to balance this critical system of developing countries.

3. Pavement Failures and Standard Procedures

It is observed that, standard and formal procedures are not fulfilled during pavement construction, resulting into a non-resistant structure [17]. There could be several reasons of improper or inadequate road surfacing such as insufficient material application, subgrade infiltration, poor material design aspects, material dislocation, in-consistent pavement properties with available geometric design features, non-mechanistic overlay techniques and drainage design [18]. This may lead to inappropriate ESALS calculations during design and analysis. Ultimately, it causes a number of surface cracks or distresses to appear at the topmost layer of pavement [19]. On the other hand, it may be transferred in terms of structural failure towards pavement's subgrade. It is quite evident that the pattern of distresses varies with a particular type of pavement like Rigid, Flexible and composites. The influencing factors are generally related to smart use of pavement materials while considering standard operating procedures and pre-construction experimentations [20]. There are various methods available for assessing pavement to which its physical condition may be observed accordingly. In this connection, devices are also available that allow practitioners to check various types of distresses and road cracks while quantifying specific distress level scales. In most cases, the video tapping method is preferable in this approach. Similarly, the Pavement Condition Indices Survey (PCI Method) is another viable option. In this method, a road section is divided into smaller sections to obtain a signified results, and similar sections of road are then taken into account by standard survey procedure. This procedure is tailored by the stepwise calculation of useful indices [21]. The technique is entirely dependent on the enumeration of indices that are to be recorded in the tabulation sheet. Besides that, the marginal values are also opted using the standard deduct value curves. Reference [22] pointed out that, pavement faults and failures are not giving serious considerations in most developing countries. There are several direct or indirect parameters which cause these failures. Direct parameters are related to development procedures whereas indirect parameters are more vulnerable to traffic injuries suffered by different types of road users. Furthermore, this issue is also associated with other factors like traffic distribution, driving skills and road faults [23]. Therefore, it is required to make a clear combination between improved pavement performance and identified distresses through formal techniques identifying road traffic injuries. This will ensure a safe infrastructure as well as high mobility for everyday users.

4. Road Traffic Injuries and Vehicle Ownership

Every metropolitan city in Pakistan has a strong and direct relationship between census indices and private vehicle ownership. At this stage, the unexpected increase of road crashes has come to an end. However, road traffic injuries are increasing day by day across the world [24]. Solutions in terms of safety measures are proposed by developed countries in order to launch appropriate techniques. It includes infrastructure management, Intelligent Transportation system, the application of GPS, and low and high-cost treatments of road furniture with short-term and long-term measures [25]. The measures installed in the road environment are meant to benefit road users who are the leading players of the road [26]. Traffic patterns and safety matters are usually observed non-uniform in developing countries [27]. In motorized countries, vehicle ownership and the rate of traffic accidents are inversely proportional to each other [28]. Hence, it is required to develop guidelines for predicting the pavement condition of an area to withstand fault patterns expected in the future. A particular study reveals the development of condition distribution graphs and maintenance plan components in response to pavement condition surveys [29].

5. Parameters of Traffic Safety and Distress Identification Methods

Employing standard guidelines, safety investigations are carried out in two major domains; traffic injury data and distress identification methods [30]. Primarily, injury data should be used as a benchmark for the relevant study. Later, the data screening is established using appropriate PCI surveys [31]. These surveys are intended for a thorough study of distress. Apart from that, rectifications are proposed based on laboratory evaluations as remedies or prevention [32]. Laboratory analysis is categorized in terms of the type of pavement and structural feasibility. On a standard note, there are similar methods accessible for various types of pavements, for example, rigid and flexible, but sample standards are quite different in connection to subjected questionable root cause or noticing faults [33]. Because education, engineering, and enforcement are the primary controls in any traffic accident, corresponding investigations must be conducted in accordance with them [34]. The dominating factors in support of the engineering perspective are represented as follows in Fig. 1. In this connection, the perspective is to interpret the pavement associated aspects that are interrelated with the occurrence of similar type of accidents. Likewise, to provide overlay in the form of patches and provision of textured transverse bars on major corridors.

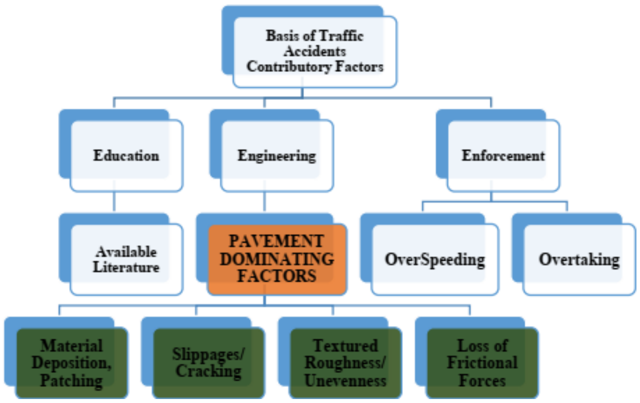

Fig. 1. Pavement dominating factors in traffic accidents

6. Significance of Lagrange Polynomial and Correlation Measures in Blackspots Identification

When unequally spaced data is provided for analysis, Lagrange Polynomial is developed and prescribed conditions are followed [35]. This polynomial is useful for determining interpolation and extrapolation analytical studies [36]. There are certainly other methods available for interpolation or extrapolation but with certain limitations [37]. Lagrange is normally used to approximate the results considering realistic features. Additionally, this type of analysis is also useful to predict quick results with more precision and accuracy [38]. The polynomial technique is more common in predictions or interpretations of numerous fields including medical, engineering, business, etc [39]. The generalized form of the equation for calculating Lagrange Polynomial is as follows in Eq. 1.

$$L_i = \prod_{\substack{i=j=0 \\ i \neq j}}^{N} (x - x_j)/(x_i - x_j) \qquad (i = 0, 1, 2 \qquad j = 0, 1, 2) \qquad (1)$$

On the contrary, correlation measures are intended to be used to categorize the data by own choice of interest. The important aspect of the correlation technique is the identification of base value and its on-going analysis between questionable rows or columns in tabulation [40]. The correlation technique is widely used in most applications depending upon the nature of analysis. In fact, in engineering applications, this method is considered to select the most optimal data for target evaluations [41].

To figure out which road accidents were caused by pavement failures, and which were caused by other factors, initial data from a trauma centre and directions from safety audits and accident investigations will be used. Additionally, the data sets are further processed by producing a Lagrange Polynomial for predicting the number of traffic accidents in future (given data is unequally spaced). Similarly, the data derived for predicted years is further redefined through the analysis of Correlation later to pick the working year and focusing traffic crashes due to road distress. The organized data sets are mechanized to prepare the list of blackspots for Karachi city in accordance with the implementation of road safety audits and accident investigations.

7. Research Methodology

In line with the objectives of the research, the complete work is sub-divided into two phases. In the first step, the existing data is gathered or collected from an injury surveillance source in Karachi city, focusing on the network of collection of traffic accident data. The data was collected from five major hospitals of Karachi including Jinnah Post Graduate Medical Centre (JPMC), Civil Hospital, Karachi (CHK), Abbasi Shaheed Hospital (ASH), Liaqat National Hospital (LNH), and Agha Khan University Hospital (AKU) [42]. The scheme of data has been coordinated in various strategies by the interviewing department, data punching department, data operators and analytical department, engineering department and stakeholder's group. The particular trauma centres are taken into consideration as covering the major arterials of Karachi. However serious traffic crashes are also reported in similar centres on a usual basis. The categories of reported accidents were varied in terms of their severities therefore, it was needed to enlist such accidents that are directly or indirectly related to pavement contributory factors. The reported factors are to be mentioned based on the preliminary knowledge of the deputed staff or existing trauma centre's classification; hence these must be reproduced with standard names of road distresses after complete assessments in audits and investigations. This entire data was limited to particular years due to specific constraints; the data was represented similarly to reflect the understanding of its increasing and decreasing trends. To idealize this factor, roads of Karachi city are assembled about the traffic stream of entire zones, or in other words, buffer zones are developed to monitor the specific crash pattern. By introducing the Lagrange Polynomial, the data is extended to inculcate road traffic accidents due to pavement faults for future years till 2025 (depending on the questionable year) as an important outcome of phase-I. The polynomial is made with interpolation, extrapolation, and the standard way of doing things with each polynomial in mind.

Similarly, the accident severity for projected years is also rationalized using graphical illustrations or to again monitor the trends against pre-defined route networks or buffer zones. In addition to that, the complete assessment of different years data records was then processed by correlation measure to select the applicability of suitable years for blackspots identification. In correlation technique, the manipulated data is assessed and cross-verified with the calculations of correlation coefficients. Here, at this stage, phase-I of finding blackspots is completed using the quantitative approach of analysis. Phase-I is more elaborated in Fig. 2 below.

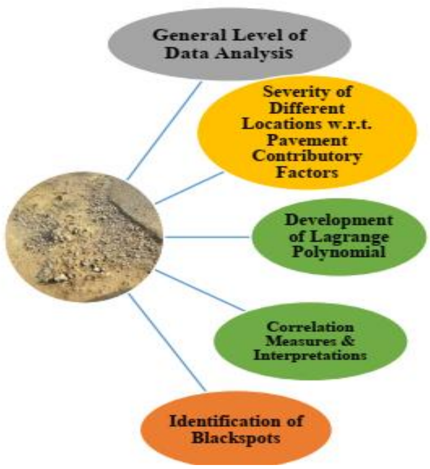

Fig. 2. Research Methodology (Phase-I): Quantitative Analysis

Phase-II or the final step is based on qualitative analysis in addition to the design of questionnaires for road safety audits and accident investigations specifically meant against the incorporation of road factors for developing countries. The focus is given to the case study of Karachi, Pakistan. The study here is aimed at re-arranging and re-ordering the blackspots fulfilling the proposed mechanism and analysis. To maintain the standards and quality of work, the questionnaires were developed in parallel to the validations received by a group of stakeholders. These include road safety consultants, road safety experts, Motorway Police, National Highway Authority, and Public and Private Organizations. Audits and investigations questionnaires and their further analysis are discussed in detail in separate sections. On the contrary, safety audits are procured on identified blackspots however the list was further refined for accident investigations during road safety audits considering the need for onward inspection. At the end of phase-II, as given in Fig. 3, blackspots were re-organized based on qualitative approaches which is the representation of devised mechanism to explore a set of severe locations experiencing serious road traffic accidents of road users due to pavement distresses.

Fig. 3. Research Methodology (Phase-II): Qualitative Analysis

8. Tools and Methods

This part is more related to a detailed analysis of the complete research study. It includes the substantial trauma centre's classification, accident severity of different locations against derived classification, and implications of Lagrange Polynomial and Correlation techniques in support of audits and investigations. The prescribed techniques are well suited on the research data and its further implications to derive a network strategies. Above all, the methods and tools are fully functional with the standard mathematical limitations in response to the collected data.

8.1 Accidents due to Pavement Contributory Factors

As already mentioned earlier, the data is filtered for a list of locations in Karachi city with a focus on pavement contributory factors. These factors are stated as per the data record of a trauma centre. Initially, the classification of contributory factors includes Road Surfacing, Road Alignment, Deteriorated roads, Road Slippages, Road Pavement issues, Dilapidated roads, and Uneven Surfaces. Sample analysis is represented in Fig. 4 and Fig. 5 showing the traffic accidents due to pavement factors or faults on assigned route networks of Karachi. Route networks are defined considering the traffic stream of particular buffer zones.

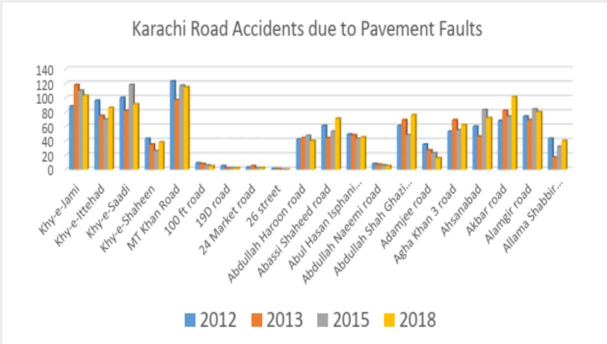

Fig. 4. Karachi road accidents due to pavement faults – Sample-I

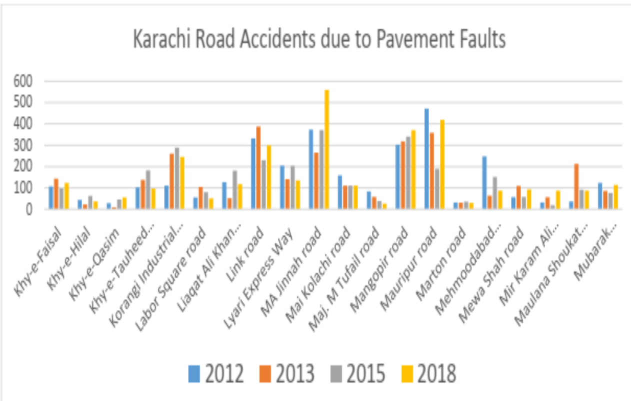

Fig. 5. Karachi road accidents due to pavement faults – Sample-II

As it is observed from the above analysis that mixed trend is reproduced for accident severity so it is further required to undergo the analysis for the identification of blackspots. On the contrary, the data is more focused on the years 2012, 2013, 2015 and 2018 for a set of route networks so it is also required to extend the data with some polynomial technique which may be useful for practitioners to find out the traffic accidents of particular years of their interest. The limitation is attained by this research study using novelistic approaches of Lagrange Polynomial and Correlation. Severe accidents are opted due to pavement faults conditioned to prescribed issues however the severity of roads is also dependent on the reported trauma centre of the city as available within the premises of the crash point.

8.2 Lagrange Polynomial for Traffic Accidents due to Pavement Faults

Considering a standard equation and existing data, Lagrange Polynomial is developed to further extrapolate the traffic accidents in this research. It is given as follows in Eq. 2.

$$P(t) = L_i P_i = L_0 P_0 + L_1 P_1 + L_2 P_2 + L_3 P_3 \tag{2}$$

$$L_0 = (t - t_1)(t - t_2)(t - t_3) / (t_0 - t_1)(t_0 - t_2)(t_0 - t_3)$$

$$L_1 = (t - t_0)(t - t_2)(t - t_3) / (t_1 - t_0)(t_1 - t_2)(t_1 - t_3)$$

$$L_2 = (t - t_0)(t - t_1)(t - t_3) / (t_2 - t_0)(t_2 - t_1)(t_2 - t_3)$$

$$L_3 = (t - t_0)(t - t_1)(t - t_2) / (t_3 - t_0)(t_3 - t_1)(t_3 - t_2)$$

Where,

P (t) = Polynomial required for Traffic Accidents in a specific year

P_0 = Traffic Accidents in the year 2012

P_1 = Traffic Accidents in the year 2013

P_2 = Traffic Accidents in the year 2015

P_3 = Traffic Accidents in the year 2018

L_0, L_1, L_2 and L_3 = Lagrange Coefficients

t_0 = Year 2012

t_1 = Year 2013

t_2 = Year 2015

t_3 = Year 2018

t = Questionable year

8.3 Lagrange Programming to Quantify Traffic Accidents for Projected Years

The polynomial was established with the understanding as discussed in the former heading. This procedure is carried out to quantify the number of traffic accidents caused by pavement faults for the required years. The roads were given numbers while symbols for years and accidents are t0, t1, t2, t3, and P0, P1, P2, and P3 respectively. Sample data for a particular road is tabulated in Table 2 and Table 3 calculating the number of accidents for the years P(2024) and P(2025) respectively through Lagrange.

Table 2

Quantification of road accidents through Lagrange – Sample-I

Lagrange Programming to Quantify Traffic Accidents for the year 2024

Road No	Years (t)	Symbol	Accidents (P)	Symbol	Lo	L1	L2	L3	P(2024)
	2012	to	88	Po					
	2013	t1	118	P1					
	2015	t2	110	P2					
1	2018	t3	103	P3	-33.00	64.80	-44.00	13.20	1262

Table 3

Quantification of road accidents through Lagrange – Sample-II

Lagrange Programming to Quantify Traffic Accidents for the year 2025

Road No	Years (t)	Symbol	Accidents (P)	Symbol	Lo	L1	L2	L3	P(2025)
	2012	to	88	Po					
	2013	t1	118	P1					
	2015	t2	110	P2					
1	2018	t3	103	P3	-46.67	91.00	-60.67	17.33	1743

It is quite evident from Lagrange programming that future accidents are predicted concerning road faults. The quantification is providing the trend of the situation using the minimum required data which is the usability of this modelling technique.

8.4 Projected Year wise Accident Severity after Attainment of Lagrange Polynomial

After full attainment of Lagrange Polynomial, the data is further analysed on the pre-defined buffer zones of roads. Graphical illustrations of similar sample data are shown in Fig. 6 and Fig. 7.

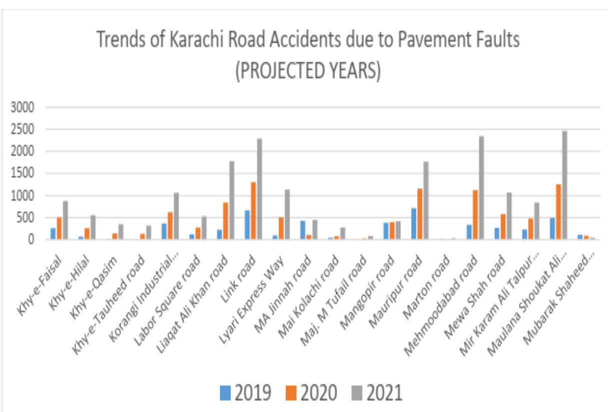

Fig. 6. Projected road accidents due to pavement faults – Sample-I

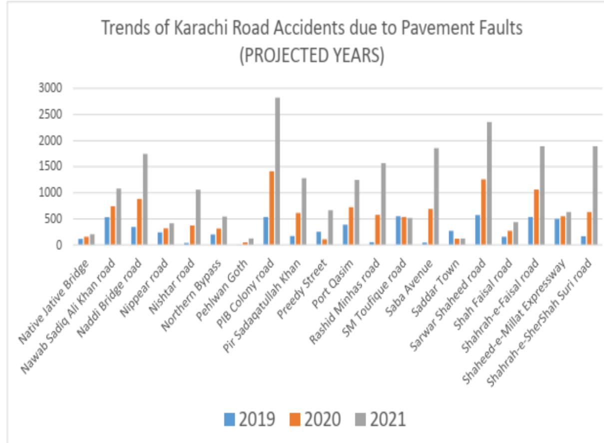

Fig. 7. Projected road accidents due to pavement faults – Sample-II

It may be observed from the above analysis of years 2019, 2020, and 2021 as the outcome of Lagrange Polynomial; the critical year is 2021 identifying the increasing trend of road accidents on major arterials but it must be verified through Correlation which is also the integral part of the analysis. Similarly, an increased crash rate is observed in Lagrange for upcoming years. The particular polynomial technique may be accommodated with the cumulative increase of crashes for identified years about pavement failures. The rate of accidents after the attainment of the Lagrange polynomial is produced in condition to the existing traffic flow pattern and connection between the years of interest.

8.5 Applicability of Correlation Technique to select suitable Year

Further to select a particular year from the prescribed list for the identification of blackspots; it was needed to apply some mathematical tools which will help in finding the most appropriate and optimized year for work. In this connection, the correlation tool is implemented within the group of data in support of the evaluation of correlation coefficients. These coefficients are characterized for the research based on the standard criteria. The calculated correlation coefficients from the year 2012 to the year 2021 are explained in Table 4 below.

Table 4

Comparison of Correlation coefficients among different years with standard specifications

Years	Correlation Coefficients	Comments
2012	Base Value	
2013	0.865648	Very Strong
2015	0.860386	Very Strong
2018	0.917183	Very Strong
2019	0.798797	Strong
2020	0.859745	Very Strong
2021	0.964251	Very Strong

In correlation, proximity towards '1' is taken into account. Hence, the year 2018 and the year 2021 has got correlation coefficients more towards '1' which are '0.917183' and '0.964251' respectively. Therefore, for this kind of data, 2021 (Very Strong) may be chosen for the ranking of blackspots at phase-I. To justify the selection of accident years, the trend line is also created showing the consistency of similar points between the years 2018 and 2021. The trend line is depicting the possible uniformity of the points between two data sets or in other words minimum noise in the data is critically observed. It is presented below in Fig. 8.

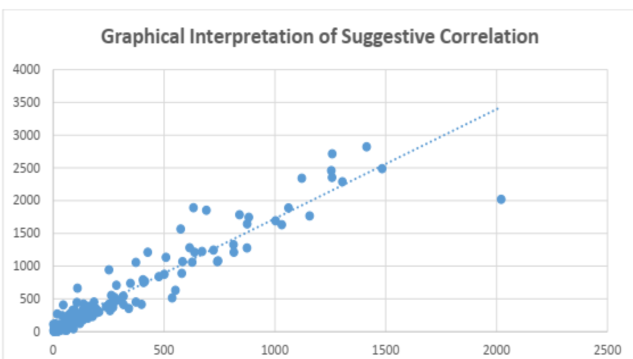

Fig. 8. Trend Line between suggestive Correlations

9. Experimentations for Road Safety Audits (Qualitative Inspection-I)

With the ranking of blackspots in phase-I and considering the accident ranges in blackspots data, 60 locations were assessed through formal road safety audits. For the same, a proper validated form is developed. The designed parameters for this inspection are a type of corridor, type of location, high-speed zone, type of intersection, pavement standard layout, road users facilitation, shoulder standards, sight distance obstructions, lane assignment, traffic signs, parking/ loading/ unloading areas, lightening facilities, traffic calming devices, road surface, existing pavement condition and recommendation for next phase of inspection [43]. Important findings for road safety audits are discussed in detail further. A synchronization flowchart is presented in Fig. 9 which is giving the brief overview of the connection of all parameters of road safety audits.

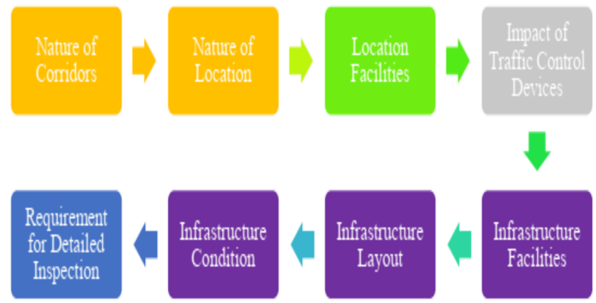

Fig. 9. Synchronization within road safety audit form

9.1 Type of Corridor in Physical Inspection-I

The corridors are characterized during road safety audits as Principal Arterial, Minor Arterial, Collectors, and Locals depending upon the traffic flow. The observation reveals more than 40% data collection from principal arterial which is understood due to the gradual increase of flow pattern while this particular data is more oriented for collectors as most of the affected ones are interlinked with these arterials. The graphical illustration is discussed in Fig. 10 below.

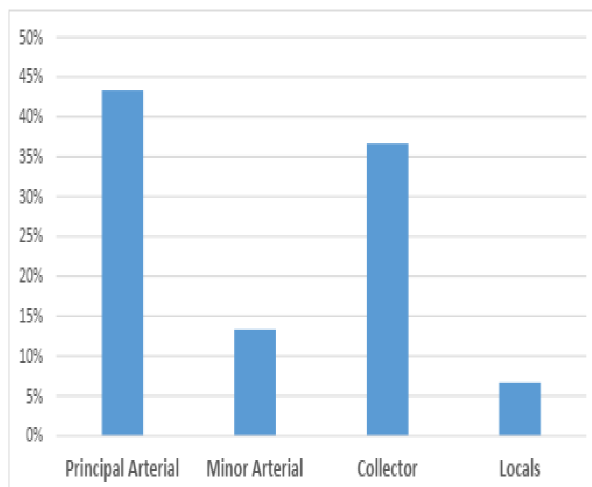

Fig. 10. Percentage of corridors in road safety audits

9.2 Pavement Layout and Infrastructure Ranking

For layout and infrastructure ranking with a focus on pavement and geometric requirements; the standard is set out with the classification as meeting standards, adequate facilities, moderate facilities, insufficient and unsatisfactory cases. The idea is more pronounced in

Fig. 11. It is apparent from the analysis that the data record is based on inadequate pavement performance so it is eventually desirable to prepare short-term and long-term actions for the locations within the respective domains.

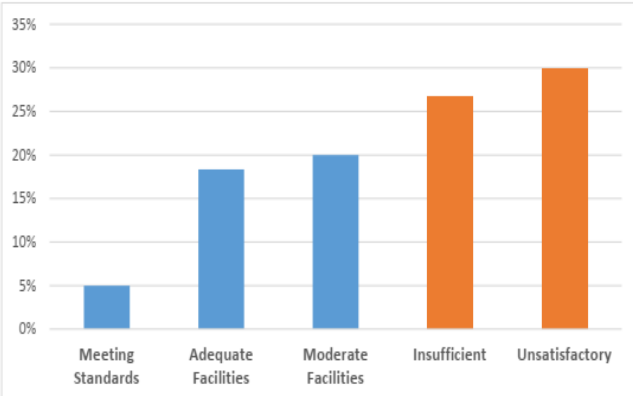

Fig. 11. Standardized grouping for infrastructure facilities

According to the above findings, around 60% of the whole data resembles the standard criteria of insufficient and unsatisfactory layout and infrastructure facilities. At this stage, these facilities are checked for geometric and pavement requirements both. It is desirable to adopt the procedures for such improvements to decrease road traffic accidents for the vulnerable road user groups. There should be a proper balance in meeting the geometric, pavement, and road safety standards while all must ensure the facilitation of road users at first instance.

9.3 Road users Facilitation

Installation of necessary facilities for standard types of road users should be noticeable as improving facilities of the road users shall ultimately enhance the mobility of roads. Road users may include Rider, Pillion Rider, Drivers, Passengers, Pedestrians, and other modes. The facilities are analysed as per the standard criteria for safety audits in Fig. 12 below.

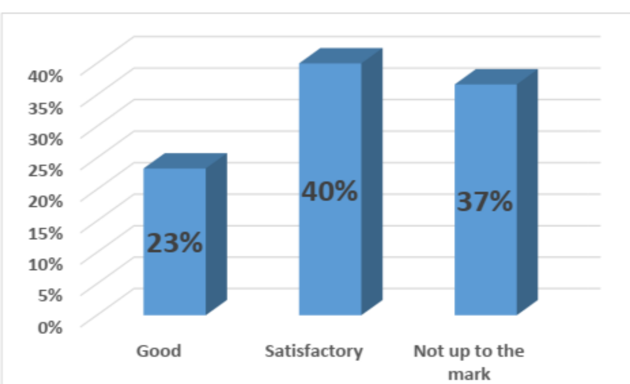

Fig. 12. Graphical illustration for road users facilitation

It is perceived from the analysis that the ranking grades of facilities under the 'Satisfactory' and 'Not up to the mark' domains are nearly the same. The facilities should be proposed by the nature of traffic and road user behaviour in particular locations. Specific actions should be proposed and executed on a timely basis against sufficient maintenance procedures for allied facilities of road users. These may include enhanced riding quality of the pavement for drivers, improvements in the at-grade and grade-separated crossings for pedestrians, Bus-Bay and interconnected bus stops with pedestrian bridges facilities for passengers and pedestrians, and textured surfaces for riders to control vehicle speed. Measures that are accounted for pavement surfacing must be examined in terms of their applicability on particular road sections. In such circumstances, preliminary proposed solutions are to be monitored and observed by establishing impact studies.

9.4 Lightening Facilities

The observed lightening facilities in different locations are graphically examined in Fig. 13 below.

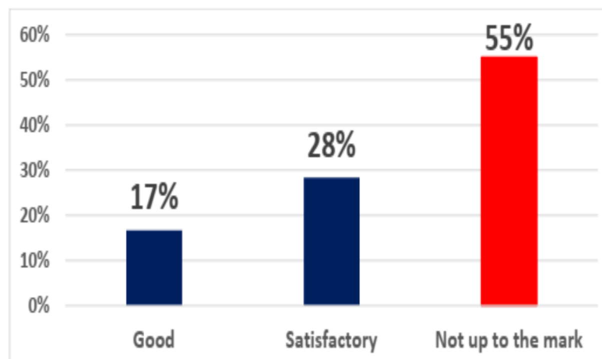

Fig. 13. Percentage of lightening facilities in different locations

As per the statistics, the percentage of lightening facilities for the 'Not up to the mark' case is 55% which is quite high. Usually, when lightening facilities are not provided adequately, it may lead to experience of traffic accidents due to bleeding action and reflective cracks on pavements. The drivers are unable to look at these specific types of distresses if the location is not properly illuminated. Usually, such distresses are more dependent on lightening services therefore, it can be minimized with supporting infrastructure at an initial run. Further, similar distresses may be addressed through rehabilitation concerns.

9.5 Existing Pavement Condition

Another formal part of a road safety audit is the appraisal of existing pavement conditions based on standards. The desired criteria include Smooth Functioning, Appearance of Mild Road Cracks, Appearance of Severe Road Cracks, Dilapidated Roads, and Construction Work Zones. Interesting results were obtained during this analysis of identified locations. It is graphically represented in Fig. 14 below.

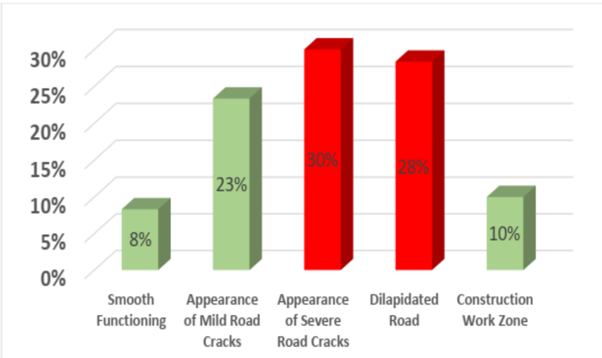

Fig. 14. Pavement condition of different locations of Karachi City

It is quite evident that more deliberations are required for severe road cracks and deteriorated roads which is the critical part of pavement maintenance and management system. Around 60% of data resembles the appearance of severe pavement cracks and even dilapidated roads in the major locations of Karachi. The area of routine and periodic road maintenance should be on high priority for concerned stakeholders to mitigate these issues. There are numerous types of cracks that require serious considerations at initial instance; if the measures are not properly accounted, they usually undergo the condition of dilapidated roads. For the sake of understanding, Alligator cracks and somehow Block cracking are taken within the group of severe road cracks (depending upon the standard deduct values). Similarly, they may be transformed into severe potholes leading towards the re-construction of the roads. Besides that, the idea is more approached towards the direct assessment and inspection of pavement through standard indices surveys.

10. Experimentations for Accident Investigations (Qualitative Inspection-II)

Screening of blackspots only through road safety audits are not sufficient therefore expanded assessments are done through accident investigations. Likewise road safety audit form; accident investigation form is also designed for Pakistan's situation (current scenario). It was intimated earlier during the safety audit that all locations will not be processed in accident investigations that is why 8 locations were eliminated at the stage of inspection-I because the relevant data findings did not reveal more in-depth investigation or qualitative inspection-II for particular 8 locations; the rest were analysed in accident investigations.

The designed parameters for the accident investigation form are road users involvement, accident types, vehicle involvement, collision types, vehicle actions at collision, weather conditions, light conditions, road character, road surface, work zone relationship, existing road infrastructure deficiencies, road, human and vehicle contributory factors, injury involvement, the rank order of pavement and geometric conditions and rank order of complete location severity [44]. Nevertheless, it is certainly required to encounter all grouped parameters of the survey and analyse accordingly instead of directly providing a severity level [45]. Likewise, for the road safety audit form, the synchronization flowchart for accident investigation is provided below in Fig. 15.

Fig. 15. Synchronization within accident investigation form

10.1 Road users Involvement in Traffic Accidents

Vulnerable road user groups are examined in accident investigations concerning the earlier classification of road users. According to the data, riders and drivers are vulnerable groups in investigated locations. The percentages are elaborated below in Fig. 16. The connection between the types of road users can be easily established by imparting supporting measures for riders and drivers however the facilities are indirectly related to calming the traffic accidents of dependent road users like pillion riders, passengers, and pedestrians.

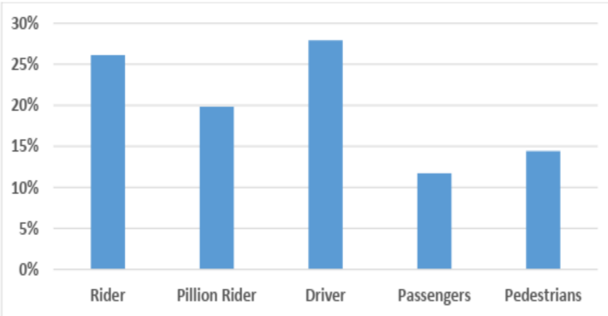

Fig. 16. Identification of vulnerable road users in traffic accident investigations

10.2 Types of Collisions in Traffic Accidents

Standard collision types are graphically represented in Fig. 17 as investigated in accident investigations.

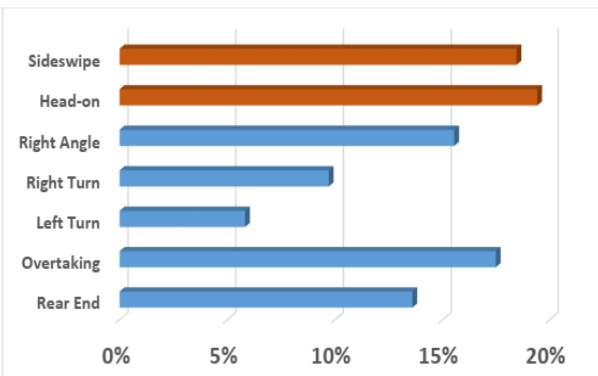

Fig. 17. Types of collisions in traffic accidents

Results showed higher percentages of sideswipe and head-on collisions on blackspots of Karachi (approximately 20% each). Such types of collision manoeuvres occur certainly on two-way unprotected roads in between the ongoing, opposite direction and overtaking vehicles to escape from the existing road distresses as observed by drivers. For such circumstances, maintenance procedures should be taken into account as earliest if the location is effected with potholes and rutting.

10.3 Observations on Pavement Deficiencies

During accident investigations, locations were also assessed for pavement deficiencies while the obtained results are as follows in Fig. 18.

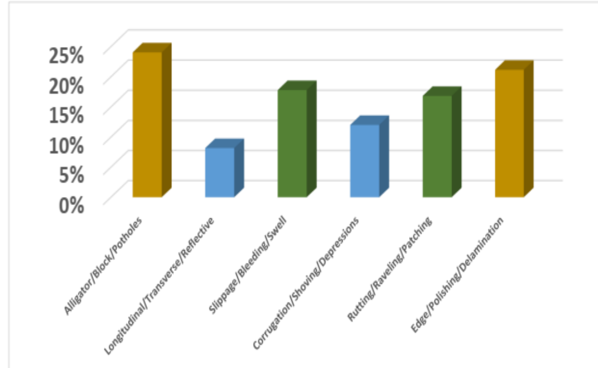

Fig. 18. Grouped analysis on pavement deficiencies

To better understand the clear picture of pavement deficiencies of investigated spots; they are grouped according to the nature of distresses. The city of Karachi is mostly observed as around 50% with distresses like Alligator cracking, Potholes and Delamination. Furthermore, this percentage is around 40% when comes under the domain of Bleeding and Ravelling. On an average note, the surveyed locations of Karachi city are functional with the existence of 45% road distresses which may include Alligator cracks, Block cracking, Potholes, Slippages, Bleeding, Rutting, Ravelling, Patching, Edge cracking, and Delamination which is a quite alarming situation. This will further help in finding out the required blackspots using this ideal approach of analysis. Nevertheless, road cracks could be proportioned by preventive maintenance, major rehabilitation, and re-construction concerns but the system should be monitored on a gradual basis using the appropriate technique of PCI surveys.

10.4 Rank Order of Pavement Condition

As depicted in Fig. 19, pavement condition is ranked out concerning the standard classification. Collectively, two rank orders with the entitlement of ‘Serious Condition’ and ‘At Risk’ has got higher percentage i.e. around 65%. The percentages result on the basis of physical inspections and observed condition of pavement which daily commuters are experiencing in the form of severe road traffic accidents. The system is in needs to consider highlighted rank orders for future development.

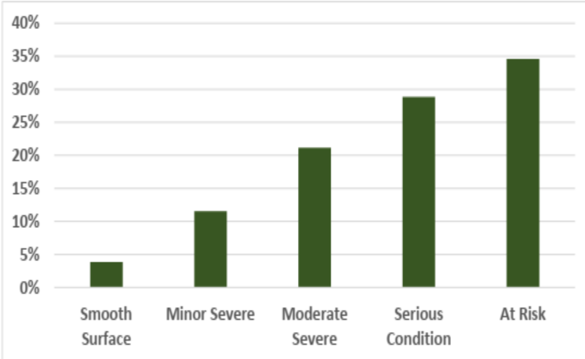

Fig. 19. Rank order of pavement condition

The above data exhibits that stakeholders must not only look for serious conditions of pavement to rehabilitate further as for the said purpose; more cost is required in road infrastructures. Despite of that, road maintenance and management system should be strengthened by all means where monitoring is taken on a serious note even in the case of minor and moderate severity of pavement (road condition). Effective and sound maintenance of pavement corresponds to cost-effective solutions for the practitioners rather to adopt detailed procedures of re-surfacing and re-construction. In this regard, a dedicated team should be deputed who will be responsible for managing and organizing such infrastructure related activities as per the requirements and work's urgency.

10.5 Rank Order of Complete Location Severity

Finding out the complete location severity in the overall accident investigation analysis is the most critical part which is graphically represented in Fig. 20. Featuring statistics, 67% of data corresponds to 'Most Severe' location severity in accident investigations.

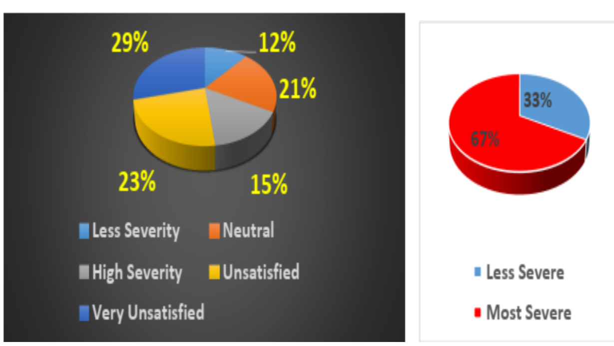

Fig. 20. Grouped location severity for screening of blackspots

At this part of the analysis, blackspots shall be redefined and reordered by the complete mechanism and ranking between 'Less Severity' to 'Very Unsatisfied'.

11. Full Categorization of Blackspots

The output of the data shall only be justified with the exploration of blackspots in complete analysis. A comprehensive list of blackspots is provided in Table 5.

Table 5

Blackspots ranking

Blackspots Ranking	Locations based on Statistics	Locations Re-order based on Surveys
1	PIB Colony road	Mauripur road
2	Tipu Sultan road	Shahrah-e-Orangi
3	Shahrah-e-Firdousi	Korangi road
4	Maulana S.A.Khan road	Kati Pahari road
5	Sarwar Shaheed road	Shahrah-e-Quaideen
6	Mehmoodabad road	Korangi Ind Area road
7	Link road	Hakim Ibn-e-Sina road
8	Shahrah-e-SS Suri road	Shahrah-e-Zahid Hussain
9	Shahrah-e-Faisal road	West Wharf road
10	Saba Avenue	Labour Square road
11	Liaqat Ali Khan road	S M Toufique road
12	Mauripur road	Shah Faisal road
13	Naddi Bridge road	Bakra Piri
14	Sir Shah Suleman road	Nippear road
15	Usmania road	Ch. Fazal Ellahi road
16	Shahrah-e-Orangi	Mehmoodabad road
17	Rashid Minhas road	Liaqat Ali Khan road
18	Hub River road	Naddi Bridge road
19	Pir Sadaqatullah Khan	Usmania road
20	Korangi road	Port Qasim
21	Port Qasim	Mewa Shah road
22	Kati Pahari road	Nishtar road
23	Shahrah-e-Pakistan	Preedy Street
24	Shahrah-e-Usman Ramz	Hussainabad road
25	Tariq road	MA Jinnah road
26	Lyari Express Way	Abd Shah Ghazi road
27	Nawab S.A. Khan road	Ahsanabad

28	Shahrah-e-Quaideen	Maulana S.A.Khan road
29	Mewa Shah road	Shahrah-e-SS Suri road
30	Korangi Ind Area road	Hub River road
31	Nishtar road	Nawab S.A. Khan road
32	University road	University road
33	Hakim Ibn-e-Sina road	Jahangir road
34	Khy-e-Faisal	Khuda ki Basti
35	Mir K.A. Talpur road	Khy-e-Jami
36	Shahrah-e-Zahid Hussain	PIB Colony road
37	Kashmir road	Saba Avenue
38	Jahangir road	Sir Shah Suleman road
39	Khy-e-Shamsher	Rashid Minhas road
40	West Wharf road	Pir Sadaqatullah Khan
41	Preedy Street	Shahrah-e-Usman Ramz
42	Shaheed-e-Millat Ex way	Tariq road
43	Khy-e-Hilal	Kashmir road
44	Northern Bypass	Kh. Gharib Nawaz road
45	Hussainabad road	Shahrah-e-Jahangir
46	Labour Square road	Mangopir road
47	S M Toufique road	Sarwar Shaheed road
48	Kh. Gharib Nawaz road	Shahrah-e-Faisal road
49	Khuda ki Basti	Shahrah-e-Pakistan
50	Khy-e-Saadi	Mir K.A. Talpur road
51	MA Jinnah road	Shaheed-e-Millat Ex way
52	Shah Faisal road	Khy-e-Saadi
53	Bakra Piri	08 Locations were excluded at Road Safety Audits Stage (Physical Inspection-I).
54	Shahrah-e-Jahangir	
55	Abd Shah Ghazi road	
56	Mangopir road	
57	Nippear road	
58	Ch. Fazal Ellahi road	
59	Ahsanabad	
60	Khy-e-Jami	

As tabulated above, the last column is the finalized identification of blackspots keeping in mind of both streams of analysis. The locations which were obtained based on statistics are qualitatively re-organized and re-arranged. Hence, the above final output is fully dependent on mathematical analysis subjected to the qualitative detailed assessments against two physical inspections. This will ascertain the whole working through advanced measures of Lagrange Polynomial and Correlation.

12. Results and Discussions

At the initial phase of the research, the data sets reveals mixed trend of Karachi's road accidents considering the available data. In fact, according to statistics, the year 2018 is more critical, but this is further extended by the development of respective polynomial and correlation techniques. Because of the variability in the traffic flow of trauma centre’s established zones, the year 2021 has a 'very strong’ correlation that ultimately corresponds to the linear relationship between road crashes caused by pavement flaws and traffic patterns on major arterials. Above all, it is a contact measure used to predict missing data and validate it using mathematical justifications. The novelty of the study is based keeping in view to connect trauma data with road accidents mathematically.

Furthermore, in order to relate the findings for the listing of blackspots, the mechanism for safety audits and investigations is re-created specifically for the Karachi city. According to the findings, approximately 60% of audits discovered insufficient infrastructure facilities, while 60% discovered severe road cracks and dilapidated roads. The locations being surveyed for accident investigations are identified as having significant road distresses, with nearly 40% to 50% of the data. It is preferable for stakeholders to conduct in-depth safety investigations using a suggested framework. Similarly, blackspots were scaled down based on location severity in comparison to qualitative assessments. The ranking of blackspots also reveals that the percentages of 'most severe' and 'less severe' blackspots are approximately 70% and 30%, respectively, necessitating the special attention of organizations to focus on pavement rehabilitation matters. The research's output represents the exploration of more than 50 refined blackspots in Karachi, followed by prescribed measures.

The research proposes the formulation of blackspots using quantitative assessments to bridge the gap between industry and academia. Besides that, the data is comprehend with the appropriate guidelines of audits and investigations. The majority of the research is based on technical interpretations and justifications, and it has been cross-verified to present a realistic picture of locations. This study only looks at five trauma centres in Karachi, but a larger network could benefit from similar approach. PCI surveys and index evaluations can assist in categorizing findings. As a way forward step, the surveys may be implicated on specified locations in order to bring with a mature framework. Furthermore, the study may also be extended to monitor and check the services using some mathematical tools in addition to the field and laboratory testings.

13. Conclusion

This specific study is one step ahead to execute a proposed mechanism to discover the kind of blackspots. The blackspots are explored in connection to the serious traffic accidents caused by pavement faults. Above all, the framework provided is one step ahead of the conventional factors of road traffic accidents which are ‘Over-Speeding’ and ‘Over-Taking’. According to the research data, approximately 80% of serious injuries are accounted for accidents due to pavement fault patterns eventually showing the significance of the study. From the overall research, the following recommendations can be drawn.

1. The research is based on the analysis of real-time features with a focus to present in an absolute way through programming and practical exposures. Hence, this study is a multidimensional way forward step in the stringent scrutiny of blackspots and safety analysis within the context of a designed polynomial equation.
2. The research is representing the relationship between injury data and substantial pavement failures.
3. Addressing qualitative analysis, injury severity is standardized in terms of minor, serious, and fatal injuries giving the exact idea to discriminate the numeric of accidents in framework.
4. The data sets against injury severity may reveal the direct relationship between the type of injury experienced by the victim and further treatment actions deployed in the trauma centres.
5. The mechanism is devised to interpret pavement faults directly or indirectly related to safety investigations.
6. The pavement maintenance and management system are signified using injury surveillance data from five major trauma centres of Karachi city.
7. The mechanism is also developed for road safety analysis highlighting all parameters.
8. In-depth evaluation of accident contributory factors for sorting out the responsible causes of pavement deterioration irrespective of the general factors like ‘Over-Speeding’ and ‘Over-Taking’.
9. Transformations and modifications are also accomplished in road safety audits, accident investigations, and associated survey procedures, mechanisms, and evaluation forms in support of road distress data and design parameters.
10. Modifications are also considered towards additional road accident trauma data identifying pavement distresses for Karachi city.
11. The framework is proposed for similar conditions in Karachi city in which blackspots could only be judged with the help of an implicit Lagrange Polynomial followed by physical inspections.
12. Procedures like Lagrange Polynomial and Correlation are being encouraged in the research while having the raw traffic accident’s data featuring with the real time statistics.
13. The process is benchmarked for identifying pavement falsities in developing countries with similar traffic scenarios concerning traffic accidents.
14. The study is generated with validated macro scale level analysis for subject pavement conditions.
15. The study may also be helpful for further experimental determinations and survey procedures to help develop an understanding of pavement cracks and material falsities.

16. In support to the data analysis and overall methodologies, the complete study is proposed to idealize the infrastructure requirements of the city which will join hands of traffic specialists, engineers, data analysts and relevant experts in an effective manner.

14. References

[1] World Health Organization, "Violence and injury prevention and disability (VIP)", Global status report on road safety time for action, Geneva: WHO, 2009.

[2] F. Ahmed Elghriany, "Investigating correlations of Pavement conditions with crash rates on in service US highways", A dissertation presented to graduate faculty of the University of Akron, December 2015.

[3] P. David Orr., "Pavement Maintenance Engineer Cornell Local Roads Program", Cornell Local Roads Program, pp. 17-40, 2006.

[4] Final Report, "The Project for Comprehensive Urban Transport Plan in Phnom Penh Capital City", Japan International Cooperation Agency, December 2014.

[5] G. Loprencipe and A. Pantuso, "A specified procedure for distress identification and assessment for urban roads surfaces based on PCI", Coatings, MDPI, 2017.

[6] I. Yut, "Case Study on Perpetual Flexible Pavement in Connecticut", Compendium of Papers from the First International Conference on Pavement Preservation, (Paper 104), pp. 1-14, 2010.

[7] A. Kassu and M. Anderson, 2018a, "Analysis of non-severe crashes on two and four-lane urban and rural highways: effects of wet pavement surface condition", Journal of Advanced Transportation, Article ID 2871451 1–10, 2018.

[8] M.M Peden, R Scurfield, D Sleet, D Mohan, AA Hyder, E Jarawan and Colin Mathers, "World report on road traffic injury prevention", Geneva: WHO, 2004.

[9] M. Abdullah Nur and M. Jamal Khattak, "Rutting Model for HMA Overlay treatment of Composite Pavements", Hindawi Publishing Corporation, Volume 2013, 2013.

[10] K. Park, K. Lee and T. Natacha, "Applicability of the international roughness index as a predictor of asphalt pavement condition", J. Transport. Res. Board, The 83rd Transportation Research Board Annual Meeting, Washington, D.C, 2004.

[11] W. Wang, M. Wang, H. Li, H. Zhao, K. Wang, C. He, J. Wang, S. Zhang and J. Chen, "Pavement crack image acquisition methods and crack extraction algorithms: A review", Journal of Traffic and Transportation Engineering (English Edition), 6(6): 535-556, 2019.

[12] N. Yeasmin, R. Zaman and I. Jahan Mouri, "Traffic Control Management and Road Safety using Vehicle to Vehicle data transmission based on Li-Fi Technology", International Journal of Computer Science, Engineering and Information Technology, Volume 6, August 2016.

[13] R. Hafizyar and M. Ali Mosaberpanah, "Evaluation of flexible road pavement condition index and life cycle cost analysis of pavement maintenance: A case study in Kabul Afghanistan", International Journal of Scientific and Engineering Research, Volume 9, August 2018.

[14] H. Mahmoud Abubakar and Z. Belel, "Road Pavement failure induced by poor soil properties along Gombi-Biu Highway", Nigeria, Journal of Engineering and Applied Sciences, June 2012.

[15] C. Murray and AD Lopez, "The global burden of disease and injury series, A comprehensive assessment of mortality and disability from diseases, injuries, and risk factors in 1990 and projected to 2020", Geneva: WHO, 1996.

[16] S. Hussain Khahro, Z. Ahmed Memon, L. Gungat, M. Razuhanafi Mat Yazid, A. Rahim, M. Mubaraki and N. Izzi Md. Yusoff, "Low-Cost Pavement Management System for Developing Countries", Sustainability, MDPI, May, 13, 5941, 2021.

[17] M. Michael Marti and A. Mielke, "Synthesis of Asphalt Recycling in Minnesota", Final report, Minnesota Local Road Research Board, June 2002.

[18] M. Mubaraki, "Highway Subsurface assessment using pavement surface distress and roughness data", International Journal of Pavement Research and Technology, Elsevier Publication, 2016.

[19] R Norman, "Extending Pavement Life by Forestalling Crack Reflection", Compendium of Papers from the First International Conference on Pavement Preservation, pp. 2-8, 2009.

[20] P. Kumar and A. Gupta, "Case studies on failure of bituminous pavements", Paper from first international conference on pavement preservation, (paper 52), pp. 1-5. 2004.

[21] M. Mazumder, H. Hwan Kim, S. Jae Lee and M. Sup Lee, "Cost effectiveness of crack treatment methods: A field study", Original research paper, Journal of Traffic and Transportation Engineering (English Edition), 2019.

[22] M.Y. Shahin, "Pavement management for airports, roads, and parking lots", 2nd ed.; Springer Publishing Company: New York, NY, USA, 2005.

[23] W. Uddin, W. Hudson, and R. Haas, "Framework for Infrastructure Asset Management", In Public Infrastructure Asset Management, 2nd ed, McGraw-Hill Education: Columbus, OH, USA, pp. 154–196, 2013.

[24] Queensland Transport, "Your keys to driving in Queensland", Accessed 7 April 2006, 2005.

[25] K.B. Woods, "Highway research and the expanded highway construction program", Purdue University, No 15, June 2000.

[26] LiY, C Liu and L Ding, "Impact of Pavement conditions on crash severity", Texas A and M Transportation institute, 2013.

[27] The World Bank, "Road deterioration and maintenance effects, models for planning and management", The World Betank, Paterson, Washington. DC, 1988.

[28] S. Nair Baskara, H. Yaacob, M. Rosli Hainin and S. Asmah Hassan, "Accident due to pavement condition - A Review", Department of Geotechnics and Transportation, Faculty of Civil Engineering, University Teknologi, Malaysia, Jurnal Teknologi, 2016.

[29] M A Hasan, B K Jrew, F H Abed and M S Msallam, "Developing a pavement maintenance management system of multi-lane highway in Iraq", 3rd International Conference on Sustainable Engineering Techniques, IOP Publishing, Materials Science and Engineering, 881, 2020.

[30] C. Plati, "Sustainability factors in Pavement materials, design and preservation strategies: A Literature Review", Construction and Building Materials, Volume 211, 2019.

[31] A. Chen, Y. Zhao, P. Li, Y. Li, M. Mohammed and P. Guo, "Crack Propagation prediction of asphalt pavement after maintenance as a function of initial cracks distribution", Construction and Building Materials, ELSEVIER. Volume 231, 2020.

[32] K Sitaramanjaneyulu, P.K. Kanchan, B.M. Sharma and M N Nagabhushana, "Indian tools for assessment of maintenance needs", 4th International Conference on Managing Pavements, pp. 1-11, 1998.

[33] "International roughness index: Relationship to other measures of roughness and riding quality", Transportation Research Record 1084. Transportation Research Board, National Research Council, Washington, D.C, pp. 49-59.

[34] A. Kassu and M. Anderson, "Analysis of Severe and Non-Severe traffic crashes on wet and dry highways", Transportation Research Interdisciplinary perspectives, 2019.

[35] T. and Y. Xu, "On multivariate lagrange interpolation", Mathematics of Computation, Volume 64, Number 211, 2001.

[36] D. Occorsio, "Lagrange Interpolation on the semi axis. A Survey", Journal of Interpolation and Approximation in Scientific Computing, Volume 2012, 2012.

[37] A.S. Cvetkovic and G.V. "Milovanovic, orthogonal polynomials", The Mathematica Package, Facta Univ. Ser. Math. Inform, 19, 17-36, 2004.

[38] K. Driver and K. Jordaan, "Interlacing of zeros of shifted sequences of one-parameter orthogonal polynomials", Numer. Math, 107 (4), 615-624, 2007.

[39] S. Kumar Roy, "Lagrange's interpolating polynomial approach to solve multi-choice transportation problems", Cross Mark, International Journal Applied Comp Math, 1:639-649, Springer, 2015.

[40] S.K Roy, D.R Mahapatra and M.P Biswal, "Multi-choice stochastic transportation problem with exponential distribution", J. Uncertain Syst,

2012, 200-213.

[41] P. Majumder and P. Pratim Ray, “A systematic review and meta-analysis on correlation of weather with COVID-19”, Scientific Reports, Nature Portfolio, 2021.

[42] “Detailed analytical report from road traffic injury research and prevention centre – RTIR and PC, Karachi, Pakistan”.

[43] S. Matsuoka, “Traffic management project in phnom penh, case study”, International Association of Traffic and Safety Sciences, 2018.

[44] S. Adeli, V. Najafi Moghaddam Gilani, M. Kashani Novin, E. Motesharei and R. Salehfard, “Development of a relationship between pavement condition index and international roughness index in rural road network”, Advances in Civil Engineering, Hindawi Publications, Volume 2021, August 2021.

[45] A. Steptoe, J. Wardle, R. Fuller, S. Davidsdottir, B. Davou and J. Justo, “Seat-belt use, attitudes, and changes in legislation: an international study”, Systematic Reviews of Road Safety Measures, 2002.

