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Validating aggregates and bitumen characteristics in road maintenance and safety management for motorizing countries using multidimensional diagrammatic models

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ABSTRACT

Maintenance and management systems are essential parameters that align with traffic safety. The dependent factors include traffic accidents on blackspots, contributory causes like pavement and geometric features, and human or vehicle issues. As per the research, more than 75% of accidents are reported due to the deteriorated conditions of the roads in a metropolitan city, Karachi, Pakistan. The consistent feature is the lack of consideration in the adopted strategies of the city, which are based on routine and periodic maintenance procedures. Unfortunately, Karachi, which has an extensive infrastructure, is seriously affected with road delaminations and cracks. Due to limited budget requirements, the city's infrastructure is deficient in pre and post-maintenance techniques. For post phases, it is required to establish the confirmatory experimental protocols for pavement sections to which road failures are observed after initial surveys and investigations. It may be directly associated with the aggregates and bitumen testing on sections of blackspots. It is evident from the statistics that around 45% to 65% of the sections are being influenced by pavement characteristics while evaluating the existing road cracks. It is also compared with the design guidelines of similar sections to identify the gaps in the existing data. The novelty in the paper deals with the usability of accident and failure data for verification of material characteristics conditioned to the industry data. The verification data entails the standard properties of asphalt. The paper enables the working of diagrammatic models in which multidimensional factors, connections of model parameters, and recommendations are elaborated.

1. Introduction

Maintenance strategies should be considered equally when compared with the design perspectives of pavements [1]. The road infrastructures are accounted for several features when planned to be executed for various types of road users. For instance, it is immensely required to check road design parameters by fulfilling the complete conditions of geometric design [2]. The features in geometric design must be proposed and in line with the design controls and criteria in addition to the cross-sectional elements of the road. The elements and road furniture on the road are to be justified with the design guidelines of the American Association of State Highway and Transportation Officials (AASHTO). Several other guidelines including AASHTO are developed

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regarding the traffic count and road capacities [3]. These are formulated through other codes and guidelines for example; Highway Capacity Manual (HCM). The road infrastructures are being designed for the users considering the existing traffic capacity by visualizing the level of services. Another important and significant part of the roads is the applicability of traffic control devices to control road maneuvers after full road construction [4]. The control devices are installed to adhere to the uniformity of road furniture and are fixed concerning certain standards, such as the Manual on Uniform Traffic Control Devices (MUTCD). Amongst all these steps, road construction is of vital importance for the concerned stakeholders. Under normal circumstances, the roads in developing countries are developed on account of the available and prescribed standards [5]. Roads are meant to be designed by giving the choice of assembly of flexible and rigid pavements and having a full approach to produce the desired thickness of the pavement. The pavement's thickness is usually accommodated by interpreting the Nomograph analysis considering the type of pavement required and suggestive highway materials [6].

The roads are planned and developed by utilizing the available standards of highways, but unfortunately, the stakeholders have very little or negligible consideration of road maintenance and management systems. This issue is very common in motorizing countries where heavy budgets are accommodated for the initial construction of pavements, but focus is not made on maintenance actions on the roads, leading to the miserable conditions of the pavement [7]. A clear comparison is drawn between the set of developed and developing countries in which a difference of around 80% is observed between the adopted maintenance procedures just after the opening of the roads. This will ensure the credibility of the proposed roads by enhancing the service life through desired maintenance actions [8]. Karachi is a metropolitan city in Pakistan, which has several arterials and collectors all around. However, it is very alarming for the stakeholders that more than 65% of roads in Karachi city are functional with the availability of serious types of road failures and distress. This is due to inadequate road maintenance actions; even though roads are not observed and assessed at regular intervals as a proposal for the type of maintenance required. It may be preventive maintenance, rehabilitation, or sometimes reconstruction [9]. Once the road is constructed in the city, it is not undertaken for further investigations, improvements, and interventions. Developed countries are practicing recognizing road maintenance actions through regular observance by the team [10]. Also, condition indices are calculated for target sections in the countries at certain intervals to identify the ranking of roads followed by the justifications for the maintenance actions [11]. At post phases, pavement-related experimentations are also carried out to bring with the confirmatory testing as part of methodical investigations. This corresponds to the closure of the complete maintenance-related investigations network [12]. Karachi city is not taken into account for having such type of studies. A little literature representing the gap is available in which detailed analysis is carried out in terms of indices on road sections of Karachi however, similar data reveals its justification by the validation of confirmation tests on the pavement particularly for bitumen and aggregates. This ensures the poor workability of the roads in the city, which is the major objective of this research. The conditions of the roads in Karachi city may be easily determined in Fig. 1.

Fig. 1. Dilapidated Roads in Karachi (Alligator and Patching)

The severe road failures observed in the city are alligator, potholes, raveling, rutting, delamination, and block cracking. For instance, alligator cracks are less harmful at initial stages but somehow when it is not treated in time, they may turn into serious types of potholes leading to the complete delamination of roads. Similarly, rutting and raveling are also interdependent. The characteristic nature of alligator and block cracks are nearly the same. Alligator cracks are also called crocodile cracks. These cracks and distresses are monitored at an intense level, which could be negotiated and accommodated at initial phases by the concerned authorities through a maintenance mechanism, but unfortunately, the condition is not like that. These faults exist on the major routes on which road users are experiencing serious traffic crashes [9]. As a main goal of the research, the faults are being checked and verified through confirmatory experimental protocols identifying the usability of the existing roads in poor condition or at the failure state. For any type of road, it is very important to consider the users' requirements by minimizing road traffic accidents, particularly related to poor pavement conditions [13]. The failures on the road surfaces may cause road accidents like skidding effects, slippage actions, and uncontrolled trajectory while driving on the roads having serious road cracks. In its broader vision, road safety is also related to controlling road users' traffic accidents, which is ideally dependent on the city's dilapidated road condition. It is only possible under the applicability of smart road maintenance and management systems including pre and post-phase analysis [14]. The pre-phase includes the general recommendations deliberating maintenance action with the provision of regular rankings of the pavements however the post-monitoring include detailed calculations on pavement indices with a focus on the experimentations on sorted sections of the roads. The ultimate goal is to benefit the users of the roads by depicting the valuable guidelines and norms which are not being accessed and approached [15]. Pakistan is below the marginal line in adopting the standard procedures to mitigate pavement maintenance, road failures, and traffic safety.

1.1 Modal Split in Transportation and its Connection with Road Accidents in Pakistan

The modes of transportation are mainly given as roads, railways, and airways, while these specific modes are accommodated for passengers as well as freight traffic. Amongst the three subdivisions, a significant share of about 90% to 95% is observed for roads in Pakistan which is quite obvious [16]. This is due to the country's increased population rate, as presented in Fig. 2. Due to the increased range in the modal split for roads, more traffic accidents are experienced in this context. As per the literature and analysis, approximately half of this share of the roads are associated with minor and severe road accidents, mainly due to the observance of the general types of surface cracks. Minor accidents correspond to the injuries that are not reported to the trauma centres however serious and fatal accidents come under the head of severe crashes and are properly documented. The cracks not only appeared on the respective roads due to the fewer maintenance measures but are also supposed to occur due to the inconsistent axle load configurations and Equivalent Single Axle Loads (ESALS) calculations during the pavement design. Hence, it is necessary to provide special attention to the roads while improving work in metropolitan cities of developing countries [17].

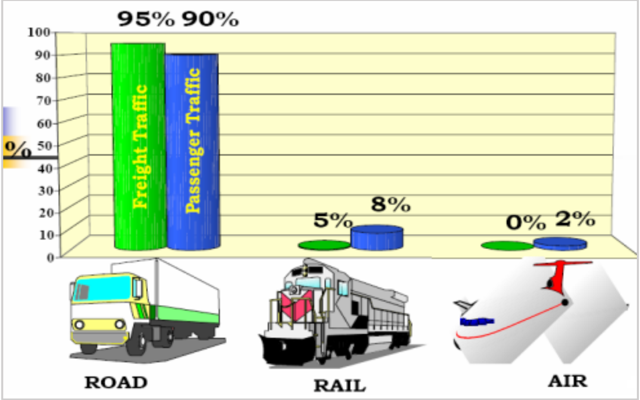

Fig. 2. Modal Share in Broad Terms [16]

2. Idealizing Pavement Failures in Road Maintenance as a Cause of Road Crashes

A series of pavement failures is depicted during the analysis and literature review of the research. It goes beyond different pavement factors and corresponds to the cause of various road accidents. As discussed earlier, road accidents are predominated by human, vehicle, and road or environment contributory factors [18]. Through complete analysis of different research, it is found that these three contributory factors are dependent on each other as given in Fig. 3.

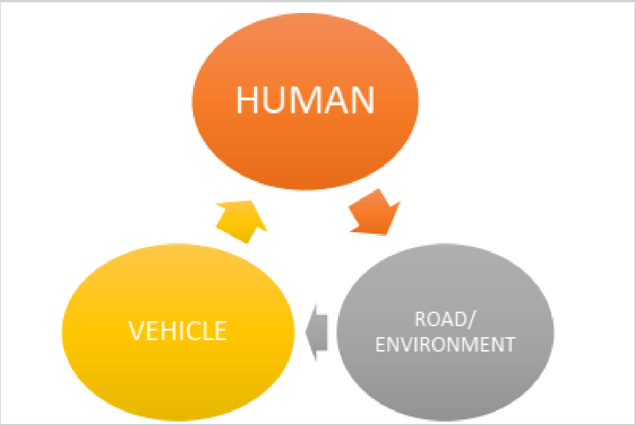

Fig. 3. Pavement Accident Contributory Factors

The three parameters depend on the accountability of accidents on a particular section of the road. If a road section is available with a series of road cracks then it is covering the perspective of road or environment features however due to the presence of road faults on the surface of the pavement, the vehicle may undergo the condition of the out of control and interrupted decision making by the road users in terms of human contributory factors. Therefore, a strong relationship is being achieved among the three [19]. As far as pavement distresses are concerned, observance of different cracks is responsible for varying reasons. It may be due to the infiltration action within the pavement, subgrade failure, flushing out of the pavement, inadequate drainage, and short or long-term aging effects. All road cracks are differentiated according to the classification of the severities as low,

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medium, and high [20]. Similarly, each type of road crack is responsible for identifying the types of road traffic accidents that occur on a pavement surface. For example, severe road bleeding may result in slippage and overturning type of accidents, as well as alligators and potholes resulting from side-swipe collisions and merging collisions. It is also observed that different types of accidents are reported, focusing on speeding and vehicles being out of control due to road delamination. It is the critical type of road failure predicted in road maintenance and management systems in which a huge volume of cracks is developed if low to medium types of standard cracks are not reported within due time of the maintenance of the roads [21].

2.1 Experimental Protocols for Pavement Characteristics Validating Road Conditions

Road conditions are idealized through pavement condition indices surveys in which an observed pavement section is ranked as per the standards. This includes categories like Very Good, Good, Fair, Poor, Very Poor, Serious, and Failure. However, considering post-analytical features, the required pavement sections are opted for further investigation against the materials used. Normally, these materials are bitumen and aggregates extracted from pavement assembly, while they represent samples of flexible pavements on urban roads. The particular investigations relate to the confirmatory experimental protocols of pavement characteristics if further macro-scale level investigations are necessary to be presented to validate the conditions of the roads. In this connection, certain standards including British Standards (BS) and American Society for Testing and Materials (ASTM) standards are available to which one may be adopted for testing of aggregates and bitumen. A set of tests may be taken in this domain likewise crushing, abrasion, soundness, etc for aggregates and penetration, ductility, softening point, etc for evaluating bitumen-related characteristics [22]. It is quite evident here that derived samples may present diversified results due to a number of reasons. The extraction of aggregates and bitumen from a sample assembly is quite a difficult task for which the quantification of the material may not be addressed properly as per the standards. Apart from that, fluctuations in the results may be represented due to the mixing of the two major pavement materials irrespective of the generation of samples via coring techniques.

The procured experimentations are performed concerning the prescribed guidelines in the standards and literature. Proper performance measures for aggregates and bitumen are discussed in the literature. The hardness and toughness of the stone aggregates are examined by crushing and abrasion tests. The crushing test focuses on the sample deformations, fractures, and collapses under the compression load capacity [23]. Similarly, abrasion is analyzed by the Los Angeles (LA) abrasion test possessing the wear of the material or aggregates. The test depends on the material's rubbing action at a specific weight. All test results must be checked using the standards of each observation [24].

On the contrary, further strength-checking parameters are observed through soundness and shape tests of aggregates. The shape test is dependent on the flakiness and elongation of the particles. The shape of the particles or aggregates in the pavement section may vary in the entire service life of the road due to the disturbance in the fractured particles and the crushing of the stones [25]. On a similar note, bitumen testing is also elaborated in the standards. The penetration test resembles the grading of the bitumen and the needle of the penetrometer that is to be penetrated in the sample. The results may vary due to the oxidation in the bitumen, aging, and the implications for weathering agents. Moreover, the ductility of bitumen is associated with the deformation and elongation of the bitumen samples for which relative distance is examined in centimeters. The test is performed through a ductility machine. The softening point and penetration tests are part and parcel of each other. This type of test is idealized by evaluating the temperature of the substance through a ring and ball apparatus in which a substance is attained to be softened [26].

2.2 Multidimensional Diagrammatic Models

The research of similar circumstances is based on the applicability of diagrammatic models extending to the multidimensional features of the complete logical framework. Multidimensional diagrammatic models recommend solutions to the problems associated with numerous dependent and independent constraints. It is also necessary to examine the cross-connections of dependent parameters in such type of models so as to ensure the viability of root cause of specific issue deliberated [27]. Similarly, these connections in multidimensional models enable us to interpret the road map for the practitioners of the relevant fields. Furthermore, these models highlight the scope of the work packages in the entire project, along with sound justifications. Apart from that, the diagrammatic models developed appropriately are readily useful to implement considering the pertinent domains [28]. The provision is made in two categories while considering this research's framework for diagrammatic models. Initially, the cross-examined

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properties are illustrated by a diagram interpreting the availability of existing data, mathematical justifications, and road factors as a source for blackspot identifications. Further, another schematic diagram is developed to interconnect the credentials of pavement experimentations as a validation in pavement maintenance. The exercise is being carried out to govern the minimization of road traffic accidents concerning weak pavement maintenance in motorizing countries by visualizing the example of Karachi, Pakistan. The focal point of the research is accompanied by the identification of pavement-related possible measures as an output of schematic models. The scope of this type of network is too wide hence the margin must be drawn within the research domain. This study briefly explains the connectivity within the experimental protocols in the pavements; however, the prerequisites are also highlighted in the models. To limit the scope of work of the paper, the results are restricted to confirmatory testing and comparison with the design values obtained from the industry.

3. Research Methodology

The research is initiated with the pre-determined blackspots of Karachi concerning the pavement ratings as deprived with pavement condition indices surveys. The blackspots are considered the target sections of the road. Apart from that, the roads are depicted in a way that focuses on the complete zones of Karachi. The city's dominating blackspots are given according to the road traffic accidents of different users standardized with the issues of pavement failures and road distress. The common causes of traffic accidents observed in the trauma data are dilapidated or deteriorated roads, road slippages, uneven surfaces, inappropriate carriageways, etc. Similarly, the ranking data of pavements is also modified in terms of poor to failure categories of road sections. In this way, selected data of poor, very poor, serious, and failure is opted from the given stream [9]. These categories are fair enough to be considered covering the scope of rehabilitation and reconstruction works after verification by confirmatory tests. Care is taken in the repetition of the roads and sections against the data of the rankings to cover the major areas of the city and incorporate number of issues in pavement experimentations for the benefit of the researchers. The matrix is given in Table 1.

Table 1
Refined Locations of Karachi city

Blackspot Name	Section	Rating
Mauripur Road	1	Poor
Shahrah-e-Quaideen	2	Poor
Hakim Ibn-e-Sina Road	3	Poor
West Wharf Road	2	Poor
S M Toufique Road	1	Poor
Shahrah-e-Orangi	1	Very Poor
Korangi Road	2	Very Poor
Korangi Ind Area Road	1	Very Poor
Sh-e-Zahid Hussain Rd	1	Very Poor
Labor Square Road	1	Very Poor
Bakra Piri	1	Serious
Ahsanabad	3	Serious
Shahrah-e-Usman Ramz	3	Serious
Kh. Gharib Nawaz Road	1	Serious
Kati Pahari Road	1	Failure
Mehmoodabad Road	1	Failure
Hussainabad Road	1	Failure
Sir Shah Suleman Road	2	Failure
Sarwar Shaheed Road	1	Failure

Considering the existing road conditions, the samples will be taken from the above sections. Therefore, 20% to 26% is set out for all the above defined ratings in the pavement sections. This ensures the balance in the selected samples that will be used for standard experimentations. All necessary experimental protocols are covered in the ratings. The protocols are fundamentally related to the tests and analysis in line with the standard specifications. The idea is explained in Fig. 4.

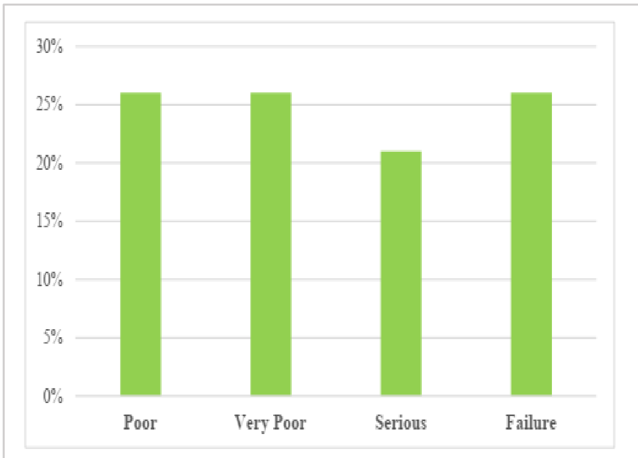

Fig. 4. Prescribed Sample Percentages for Experimental Protocols

4. Tools and Methods

The complete experimentations for the research were classified into the test results of aggregates and bitumen as the two major components of flexible pavement. The test results are generated in place of the ASTM standards. Aggregate testing comprises of Crushing Test, Abrasion Test, Shape Test, and Soundness Test however Penetration Test, Ductility Test, Softening Point Test, and Flash and Fire point Test are covered in the domain of bitumen. Here, it is quite evident to mark the difference between the

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asphalt and bitumen. Bitumen is the type of binder and filler which is mixed with aggregates to form an assembly. This assembly is called 'Asphalt' on road surfaces. For experimentations, bitumen and aggregates are assessed separately. These tests are carried out on the deteriorated pavement sections of the city for further elaborations and recommendations in the research. It is assembled in Table 2.

Table 2
Standard Tests for Aggregates and Bitumen

Confirmatory Tests	Recommended for	Standards
Crushing Test	Aggregates	ASTM D 5821
Abrasion Test (Hardness)	Aggregates	ASTM C-131-03
Shape Test (Shape Factors)	Aggregates	ASTM D 4791
Soundness Test	Aggregates	ASTM C 88
Penetration Test	Bitumen	ASTM D 5
Ductility Test	Bitumen	ASTM D 113
Softening Point Test	Bitumen	ASTM D 36
Flash and Fire Point Test	Bitumen	ASTM D 3143

The samples are collected and derived with the efforts of the entire team. On-spot undisturbed samples are generated from the selected blackspots through the specified techniques of coring in pavement engineering [9]. The tools and methods are expressed in Fig. 5.

Fig. 5. Sample Coring and Measurements

5. Experimentations for Aggregates

5.1 Crushing Test

The test is being measured on the samples of the blackspots to check the measure of resistance to crushing. Compression test is carried out under standard load conditions. The prescriptions are made by filling the cylinder into three layers, followed by the tamping action through the rod. The aggregate crushing value is enumerated through the weight of passing material and the total sample using the standard formula [29]. The trends for crushing values are generated in all blackspots or sections. A graphical illustration of the trends is represented in Fig. 6.

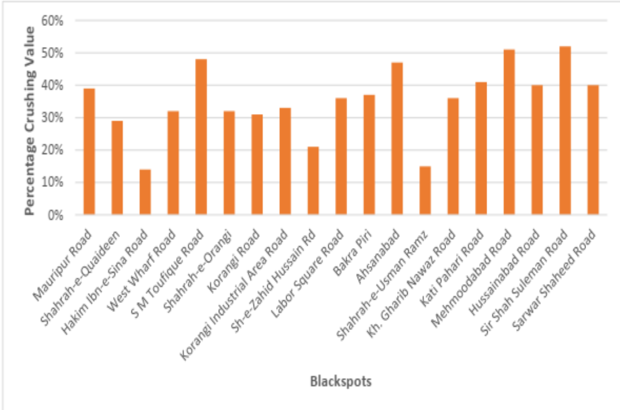

Fig. 6. Observed Trends in Crushing Values

Concerning the standards, less than 30% crushing value is considered satisfactory. All samples are presented to provide the trends comparing to the standard value. Hence, peak values are obtained on the samples of Mehmoodabad Road and Sir Shah Suleman Road, and further it is also verified from the given pavement ranking. By overviewing the satisfactory and unsatisfactory conditions of the road, it is depicted that around 80% roads of the Karachi do not impart the standards of crushing values so it may be the point of statement that most of the aggregates in the majority sections have resulted into the completion of service life. It is presented in Fig. 7.

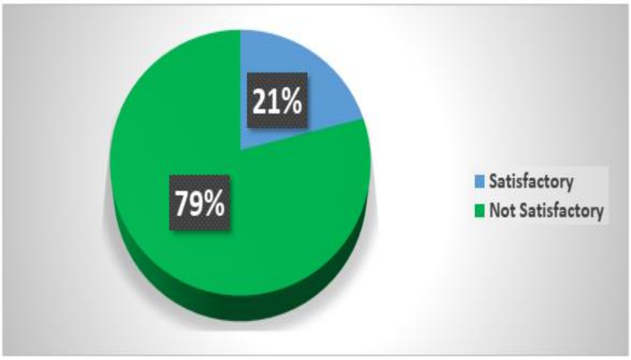

Fig. 7. Stages Percentage in Crushing Values

5.2 Abrasion Test

To monitor the hardness property of aggregates in detail, the LA Abrasion test is done. It is suitable for different pavement constructions. As per the limitations, a maximum value of 40% is allowed for the WBM base course, and for bituminous concrete, a maximum value of 35% is recommended. Likewise, the crushing value trends against this test are also generated, focusing on road sections in Fig. 8. Referring to the cases of deteriorated samples, the abrasion value should be less than 35% [30].

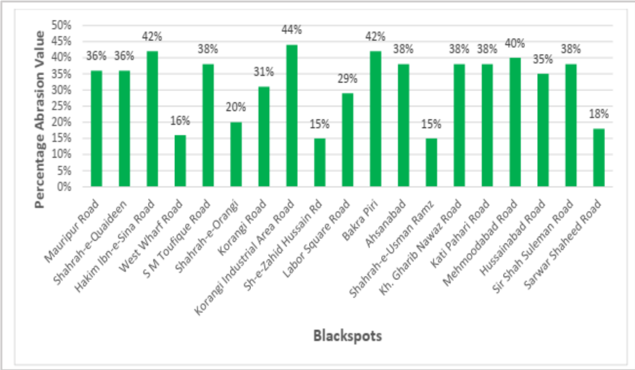

Fig. 8. Observed Trends in Abrasion Values

It is evident from the above illustration that road sections with similar percentages of abrasion values represent weak aggregates in terms of abrasion. There is a very thin line in understanding the crushing and abrasion values. Frictional forces are incorporated in such cases leading to the major cause of road accidents. Provision of textured surfaces and different surface applications may be the recommended measures in this context. Moreover, around 63% of the spots are pretending towards the unsatisfactory conditions in continuation to the calculations of abrasion values. The critical spots are Hakim Ibn-e-Sina Road, Korangi Industrial Area Road, and Bakra Piri Road.

5.3 Shape Test

Another critical parameter for judging the failure patterns on the functional roads is the applicability of the shape test. It is defined in terms of elongation and flakiness indices. These indices resemble the improper orientation of aggregates. According to the standards, the individual value should not be more than 15%, or in other words, it must not be more than 30% considering the combined indices [31]. The trends for the road sections are illustrated in Fig. 9, showing the distinct results in both the shape test scenarios. This is due to the variation in the sizes of the aggregates within the samples.

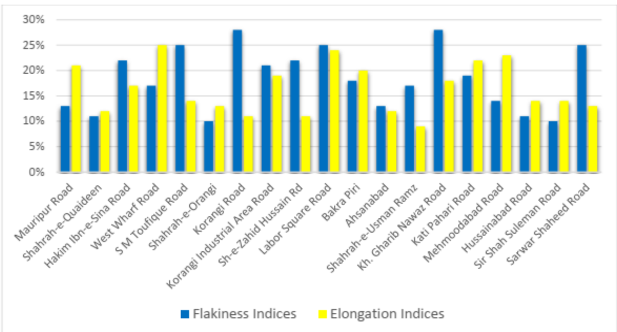

Fig. 9. Observed Trends in Flakiness and Elongation Indices

The stages percentage in terms of satisfactory and unsatisfactory is deliberated in Fig. 10.

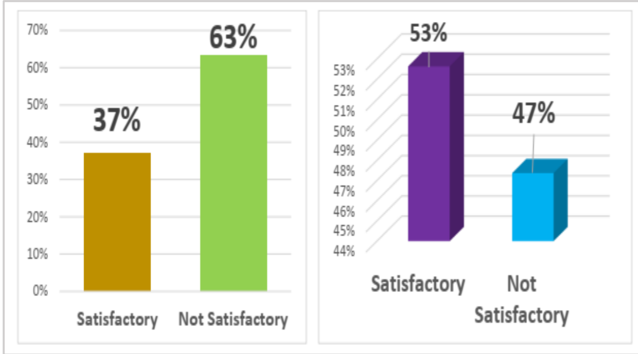

Fig. 10. Stages Percentage in Flakiness (Left) and Elongation (Right) Indices

5.4 Soundness Test

Further, to check the workability and strength of aggregates, soundness property is determined using Sodium Sulphate. A standard is less than 12% in this case, and similar trends for Karachi are shown in Fig. 11. This property enables the loss of material during the specific procedure. Under normal circumstances, it evaluates the resistance of aggregate focusing real time weathering conditions.

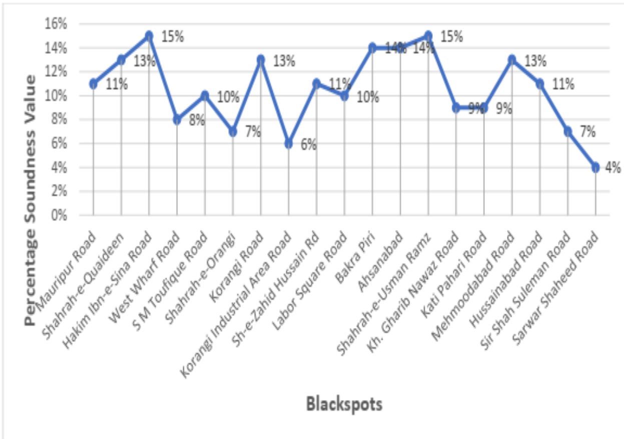

Fig. 11. Observed Trends in Soundness Values

Only 40% of the road sections identify the unsatisfactory stages in soundness values. Regarding the soundness test, the samples generated from blackspots of Karachi city are fulfilling the standards in their current conditions. Hence, technical preventive measures must be focused to similar scenarios while featuring road maintenance and management system strategies.

6. Experimentations for Bitumen

6.1 Penetration Test

Both aggregates and bitumen are assessed critically on an individual basis for the opted road samples. This is required to monitor the variations in the properties of the stone particles and the bonding material in the overall assembly of flexible pavements. Applying the proper grades of bitumen on the roads is an important issue, keeping in view the city's weather conditions. Usually, 60/70 grade bitumen is proposed for hot climates. This type of bitumen is a bit harder to penetration therefore it is observed on roads in Karachi. Due to hot weather, the bitumen may be softened with time, so initially a hard type of bitumen in terms of penetration is accommodated. Bitumen having high penetration values like 80/100 is not proposed in hot regions as the respective type is quite soft to material penetration, so there may be a chance of more fluidity in bitumen resulting in the bleeding and corrugation types of cracking. 80/100 bitumen is applicable for cold regions [32]. The analytical trends are identified in Fig. 12 however the aging phenomenon of bitumen highly influences the variations in the penetration values.

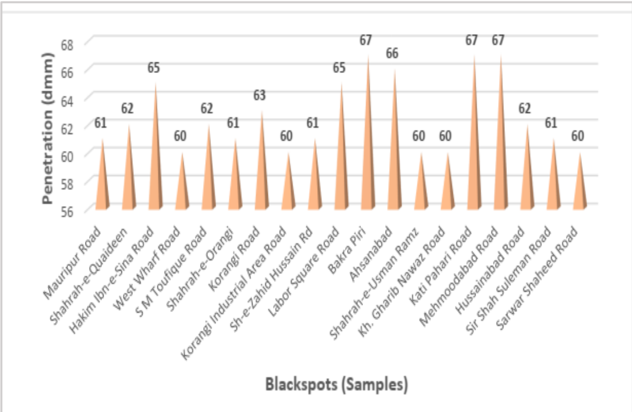

Fig. 12. Observed Trends in Penetration Values

6.2 Softening Point and Flash and Fire Points Test

Softening of the bitumen material is tested through a softening point test according to the observed temperature using standard techniques. This may depend on bitumen oxidation, aging effects, thermal effects, inadequate wheel paths, and imbalanced load transfer mechanisms. Under normal circumstances, penetration and softening points are inversely proportional to each other subjected to the volatile properties of the bitumen. The set of softening points on defined road sections along with the trends are idealized in Fig. 13.

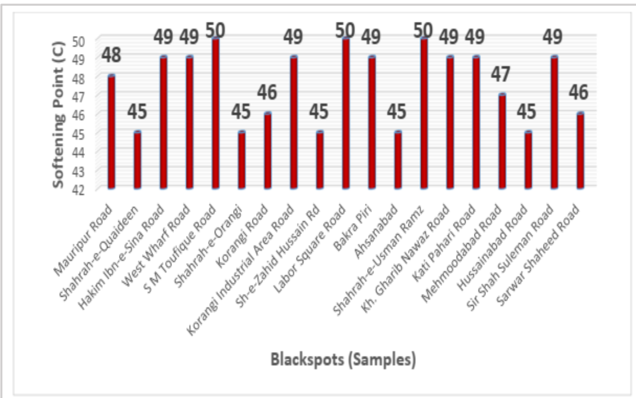

Fig. 13. Observed Trends in Softening Points

Standard measures in this domain are infiltration control, drainage control and thermal treatments [33]. On the contrary, the flash and fire points for the generated samples are tabulated in Table 3. Noise in the data is observed while noticing the trends in flash and fire points, which are commonly due to the extreme weather conditions in Karachi city, in addition to the rubbing action between the gradations of aggregates.

Table 3
Flash and Fire Points

Blackspot (Samples)	Flash Point(°C)	Fire Point(°C)
Mauripur Road	270	278
Shahrah-e-Quaideen	270	279
Hakim Ibn-e-Sina Road	240	248
West Wharf Road	220	229
S M Toufique Road	277	287
Shahrah-e-Orangi	240	252
Korangi Road	250	260
Korangi Ind Area Road	220	227
Sh-e-Zahid Hussain Rd	260	268
Labor Square Road	270	280
Bakra Piri	250	259
Ahsanabad	270	282
Shahrah-e-Usman Ramz	270	280
Kh. Gharib Nawaz Road	230	242
Kati Pahari Road	238	247
Mehmoodabad Road	260	270
Hussainabad Road	268	279
Sir Shah Suleman Road	240	248
Sarwar Shaheed Road	220	227

6.3 Ductility Test

This property of bitumen is particularly related to deformation or elongation in a synchronized manner. It is measured in centimeters considering elongation till the breaking point. The test is done on standard specimen with specified speed and temperature. In line with the standards, the observed values should be 100 cms or more for road constructions [34]. The trends are presented in Fig. 14.

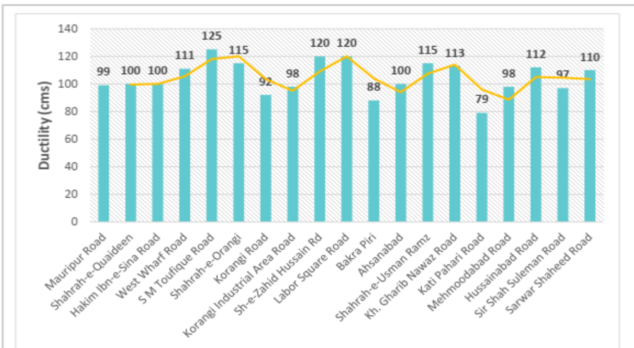

Fig. 14. Observed Trends in Ductility Values

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As per the above analysis, satisfactory results may be achieved in terms of the ductility of the bitumen. Brittle and ductile behaviors are two separate performance measures in construction materials. Brittle behavior corresponds to the sudden failure of the pavement, which is not usually observed in flexible surfaces. However, the ductile behavior is more common in flexible pavements, where indications in the form of initial cracks appear on the surface, and after a specific interval of time with continuous loading, various types of road failures may come across. Focusing on the general and specific guidelines, the solutions could be proposed addressing the induction of smart and sustainable pavement materials, for example, the implications of Reclaimed Asphalt Pavement (RAP) materials [35]. This particular solution is more viable and cost effective in terms to use the existing material with least or infact negligible transportation cost. RAP material may be easily used for the transformation of pavements and rehabilitation works instead of dumping the whole material.

7. Results and Discussions

This part is predominantly related to comparing the different analytical streams to interpret the major gaps in the field, documented, and research works. All procedures adopted for bitumen and aggregates on the opted sections of the roads are compared using suitable analytical techniques and design values. In other words, a comparative analysis is drawn between design and experimented values. The design values are taken from the available reports by the concerned stakeholders, organizations, and institutions however experimented values are governed and defined in accordance with the tests performed in the research as discussed in the earlier sections. To develop a better understanding of the research and discussions on the results, some significant comparisons are highlighted in this section to which the severity of roads may be easily justified. Provision of errors is also accounted for during the observations and analysis due to the number of factors including indeterminate test outputs and observations, limitation of material due to the extractions, actual matching of the sections while manipulating the design, and experimented values and misinterpretations in the standard reports by the organizations. Besides that, a careful investigation is carried out to select the most appropriate section, as mentioned in the research from the test reports.

7.1 Comparison between Design and Experimented Values for Aggregates Characteristics

The design and experimented values are evaluated for each category, such as crushing, abrasion, flakiness, elongation, and soundness. The analysis produces a blend of qualitative and quantitative results, which help synchronize the industry data with the research data. The design and experimented values are compared to the testing procedures for aggregates that are the prime elements of pavement. The comparison of both values for the abrasion test is given in Fig. 15.

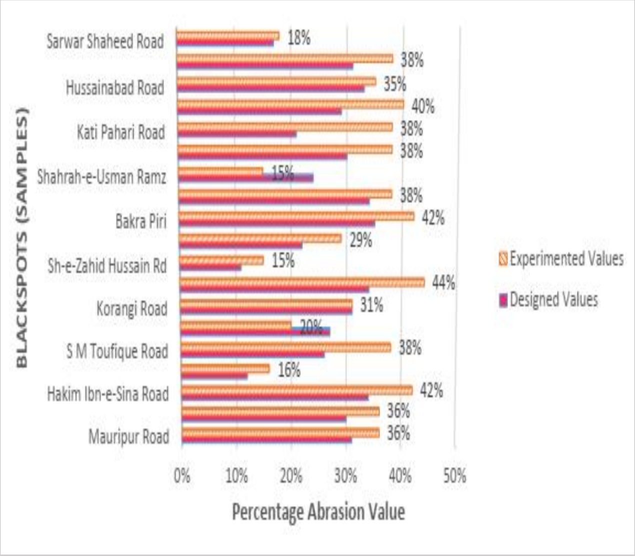

Fig. 15. Comparison b/w Design and Experimented Values (Abrasion Test)

It is predicted from the above analysis that a nominal increase in the experimented value is observed (from 11% to 15%) for Shahrah-e-Zahid Hussain Road while both values satisfy the standard limit. Interestingly, the Korangi Industrial Area Road section was designed at a very high rate for abrasion earlier; at present, it is beyond the standard limits. The cracks in this section are high-severity potholes and delamination on which vehicles are moving at the subgrade layer. The rest of the layers of the pavement have been removed from the assembly, so measures like chip sealing and availability of a stable foundation should be proposed by the concerns [36]. Focusing on the results in abrasion values, the proposed remedies are addressing the literature satisfying the conditions for adopting the measures [36].

Similarly, the comparison for the soundness test is presented in Fig. 16. As per the analysis, soundness values are observed low in experimentations as compared to the design values for the respective cases like Korangi Industrial Area Road, Kh. Gharib Nawaz Road and Sarwar Shaheed Road. The main reason behind it is the more wastage of aggregates when in execution by the number of wheel passes. For this reason, variations in the values are explored within the samples of the same section of the road, which is difficult to manage in pavement maintenance. In this domain, it is important to establish strategies for pavement construction equipment management by introducing novel construction techniques in infrastructure developments. Keeping in mind such circumstances, the soundness test is kept compatible with the shape classification of aggregates hence the solutions are in line with the prevalent conditions of the sections [25].

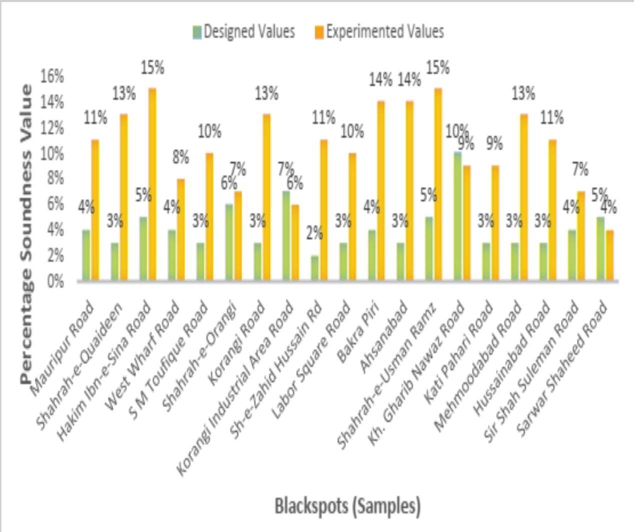

Fig. 16. Comparison b/w Design and Experimented Values (Soundness Test)

7.2 Comparison between Design and Experimented Values for Bitumen Characteristics

Complete bitumen characteristics like penetration, softening, flash fire, and ductility are compared with the design values to bring about the impacts the bitumen samples have already undergone when placed in flexible pavements with aggregates. Some of the comparisons are discussed in this section for the readers' understanding. Penetration (DMM) of the bitumen is subjected to the grading of the bitumen, enabling the hardness and softness of the material. Problems that may arise in this context are the entrapped water movement within the pavement layers leading to the longitudinal and transverse cracks. A heavy budget is required in maintenance to remove these types of cracks however avoiding such cracks may result in right-angle and rear-end collisions. The comparative analysis is established in Fig. 17 which shows the higher 66 DMM penetration on some spots at the design phase. These values must be negotiated to avoid initial surface cracks. In a similar context, significant variations are monitored in experimented values for softening points in major locations of Karachi due to the observance of warm climates. The results are generated in Fig. 18. The properties of bitumen are interrelated, covering the strength and binding constraints of the flexible-type pavement. Likewise, flash and fire points also need to be examined during the comparative analysis. By having a set of data for the blackspots of Karachi city, points of collimations are explored for design and experimented values against fire points at certain locations. The locations include Hakim Ibn-e-Sina Road, Labor Square Road, Sir Shah Suleman Road, etc.

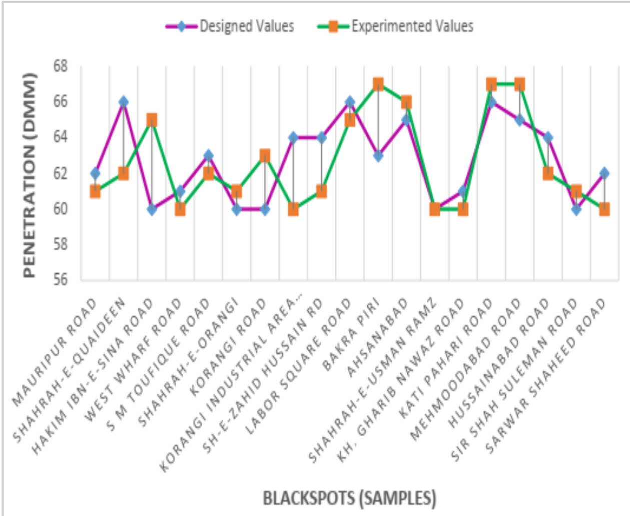

Fig. 17. Comparison b/w Design and Experimented Values (Penetration)

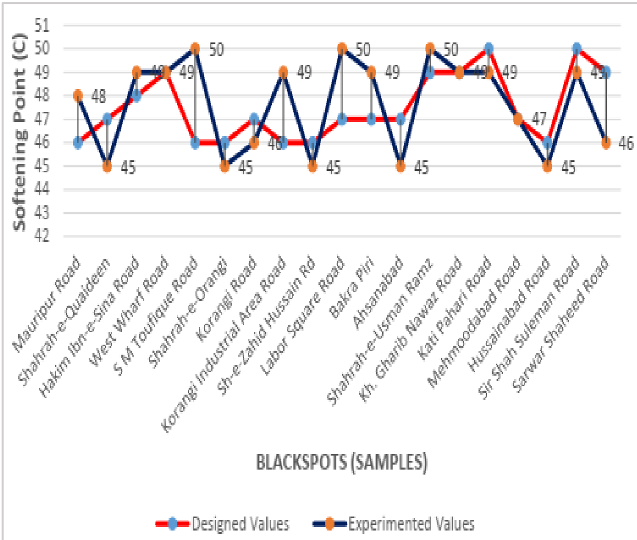

Fig. 18. Comparison b/w Design and Experimented Values (Softening Point)

7.3 Proposed Schematic Models

One of the most important outputs of this research is the generation of multidimensional diagrammatic models of transportation safety through prescribed analysis. While making the flow diagrams in the analysis, it is necessary to examine the overall parameters of the study or required network. Such models are prepared to reconnect the activities of an entire framework by mitigating the issues and controls in similar fields. The first schematic model is outlined in Fig. 19, giving a brief idea for screening the blackspots through accident or trauma data. In general, the causes of road accidents must be available in the existing trauma data to extend a similar type of analysis to the confirmatory experimental protocols of pavement.

Similarly, it should also be in the scope of the study to validate the data analysis using some analytical tools. Correlation and polynomials are the two choices that are often used in these studies [37]. As discussed above, some areas are furnished in this research using the available data but a logical framework presented expresses the guidelines by ascertaining the internal issues of metropolitan cities, such as the case study of Karachi, Pakistan. The same colors in the model depict the working mechanism in the proposed framework. However, the connectivity among the activities may be observed through the direction of arrows. The exciting part of the proposed network is the synchronization between all the entities to be focused on individual zones in the model. The model may help prepare the list of the blackspot sections initiated by trauma data and cover the mandatory road safety and pavement maintenance aspects.

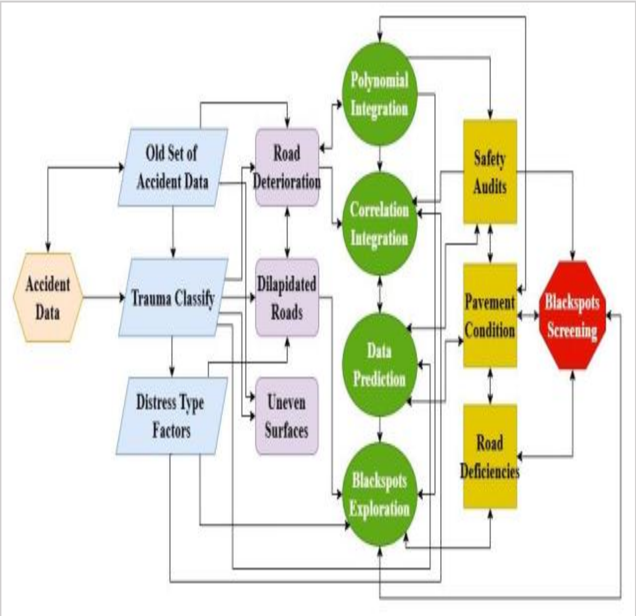

Fig. 19. Diagrammatic Model - I

The later part of the analysis is projected through Fig. 20, in which experimentations and testing are formulized for aggregates and bitumen. All experimentations are aligned in the second schematic model and are associated with the trends' modifications. As far as aggregates are concerned, the crushing and soundness properties are interrelated to each other. Crushing deals with the existence of crushed particles in the sample while soundness confirms about the toughness of the stone particles in the presence of weathering agents. Nevertheless, the experimentations are counter-examined with the illustrations of comparative analysis. In continuation of the literature, a kind of complex system is established by coordinating the overall characteristics of each cell to ensure the comprehensive model. This helps in defining the cross-linkages between the cells to produce desired outputs.

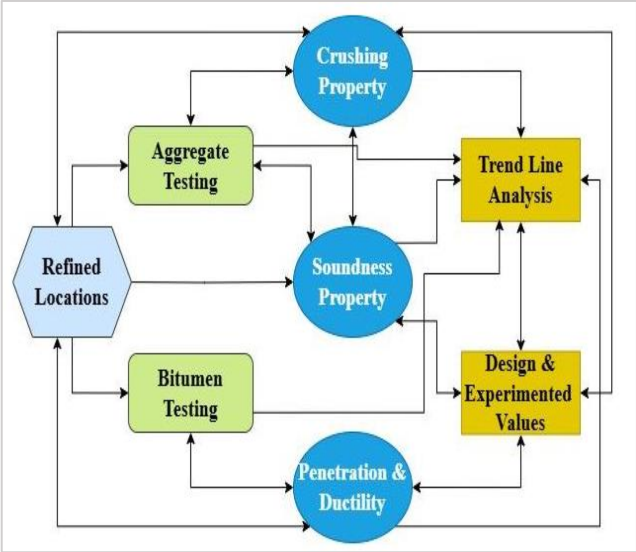

Fig. 20. Diagrammatic Model - II

8. Conclusion and Recommendations

The overall research is presenting the work in different directions. Initially, the experimental protocols are defined and categorized in line with the standards for flexible pavement components. The prime components of this type of pavement are aggregates and bitumen; hence, it is crucial to Fig. out every single aspect of the two materials that address the key attributes of road maintenance and management systems. It is verified by the research that besides the common causes of road accidents in Karachi city, one of the main reasons is the inappropriate measures for road maintenance against the observed failures of the roads. The trauma data of road accidents in Karachi reflects about 80% to 85% of fatal injuries with the common cause of road delamination. Therefore, these roads and blackspots should be classified using the appropriate pavement condition indices monitoring to rank the pavement within the given stream of categories significantly. These are the observance strategies that account for the roads of a city but post-phases may include the verification of the monitoring mechanism through pavement experimentations as discussed above, and is an integral part of this research study. The characteristics and properties distinguished amongst the experimentations are of several types, including crushing, abrasion, flakiness, elongation, flash and fire, ductility, penetration, softening, etc. The results showed the distinct properties amongst the samples opted from selected blackspots of the city. By looking at the overall analysis of the experimentations, it may be stated that the failures of pavement surfaces depend on different cross-examined properties of bitumen and aggregates. As evident from the observations, approximately 60% to 80% of road sections are not satisfying the limits of crushing and abrasion or even at the failure stages in its present condition while this percentage is about 50% for the

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observations of elongation indices. This is the phase in which the infrastructure designers may go for the specific options to control the specific property responsible for road cracks on the pavements. This type of research is useful to prioritize the measures if a heavy budget is not available for rehabilitation. The major distress types predicted on the roads to which road accidents are experienced are alligator cracks, potholes, delamination, bleeding, block cracking, and corrugations. These distress types are somehow also conditioned to the validations from the bitumen characteristics and its rheological properties [38]. As in the case of bitumen penetration, critical 67 (DMM) penetration is observed on a number of sections reflecting the softening of bitumen towards the upper range of the particular grade and further portraying the surface cracks as bleeding. Bleeding of pavement may cause serious injuries to riders and pillion riders. The bleed bitumen on the pavement surface results to the slippage of the motorcycles. Further, there is a clear difference between the definitions of the two road users; riders and pillion riders. The one who operates motorcycle is actually the rider while the passenger on that particular vehicle is called as pillion rider. Above all, the confirmatory testing in the research confirms for the above 50 percentile of the data originated from indices surveys. Similarly, the discussions are made in the paper by comparing the experimented values with the design values of similar roads. It shows that around 30% to 35% of road sections in Karachi city were executed earlier with the recommendations of organizations with critical characteristic values. These values were required to be addressed at the initial phase of the construction by suggesting some alternatives. Apart from that, there might be a chance of the connection's improper documentation of the results. The later parts of the research focus on the multidimensional diagrammatic models of transportation safety in consideration of the analysis carried out to control the relevant parameters within the scope. The proposed maintenance measures using the experimental justifications in model analysis for the list of blackspots that may prevent road traffic accidents in Karachi are identified in Fig. 21. As a matter of fact, some treatments are related to the surface applications including patching and slury seal however certain specific locations are predominated with weather, moisture, and water conditions followed by the associated controls. These include drainage treatment, thermal treatments, and infiltration control. Proposed measures are also accounted for the renovation works comprising Hot mix asphalt (HMA) mixing, and reconstruction. In this way, the complete research entails the requirement of a logical framework for the series of activities in road safety and preferably pavement safety for metropolitan cities for example, Karachi, Pakistan. Moreover, the particular study is also synchronized with the global Sustainable Development Goals (SDGs) keeping in view of the fulfilment of all objectives of the research. The goals that may be influenced with this research are Goal 4 (Quality Education), Goal 8 (Decent Work and Economic Growth), Goal 9 (Industry, Innovation, and Infrastructure), Goal 11 (Sustainable Cities and Communities), and Goal 17 (Partnerships for the Goals).

Fig. 21. Maintenance Measures for the Study

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