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THE CORRELATION BETWEEN EXISTING METHODS FOR ASSESSING THE SKID RESISTANCE OF ASPHALT CONCRETE PAVEMENTS

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Abstract
Currently, the rapid development of the automobile industry leads to an increase in traffic intensity on the roads, a sharp change in traffic flows in a short period of time results an increase in the number of road accidents. Pavement texture and skid resistance are important pavement transport-operational indicators of roads, which determines the friction between the pavement surface and vehicle tyres. Implementing optimal procedures for maintaining a sufficient texture and friction coefficient are important for minimizing road accidents. Therefore, the research discusses the measurement methodologies, correlation and resource-cost effectiveness of the mean texture depth (MTD), mean profile depth (MPD), British pendulum number (BPN) and coefficient of friction (FC) measurements on a 4R18 road in Uzbekistan.

Keywords: Pavement texture; mean texture depth (MTD); mean profile depth (MPD); British pendelum number (BPT); friction coefficient (FC); skid resistance.

Introduction

The contact between a vehicle's tire and the road surface is an essential element of road transport safety. Tire-pavement interaction and pavement texture are two major parameters that have a significant impact on skid resistance.

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The skid resistance of road surfaces is mainly expressed by the resistance of the tires to slipping or sliding on the surface of the road surface [1]. Friction occurs as a result of the close interaction between the tire and pavement aggregates. Many factors that influence road safety and ride comfort are affected by pavement texture, including friction, rolling resistance, splash and spray of water on the pavement surface [2].

The pavement may be in different conditions depending on air humidity, precipitation and other meteorological factors, as well as traffic intensity, level of maintenance and type of pavement. In the wet condition of the pavement, due to the wedge of liquid on the pavement penetrating into the contact zone of the wheel with the road, friction can significantly decrease. Under these conditions, the realized coefficient of friction is determined by a number of factors characterizing the car tire, the road surface, the liquid separating and the interaction conditions [3].

One of the main problems in the road safety sector is traffic accidents related to the loss of skid resistance below its threshold value. These high-accident pavement locations frequently have skid resistance values below the minimally safe threshold. Some research shows that 14% of all fatal traffic accidents take place during rainy conditions [4]. In contrast to rainy weather, the frictional characteristics of the pavement surface affect the frequency of accidents in dry weather as well [5]. Road accidents are a major concern for all road authorities around the world. In developing country like Uzbekistan where the fatalities rate from traffic accidents is higher than in developed countries. In 2022, 9902 traffic accidents occurred in the Republic of Uzbekistan. 9,606 (76.2%) people were injured and 2,356 (23.8%) people died in these traffic accidents [6]. Currently, skid resistance and the coefficient of friction of the pavement on road sections where traffic accidents occurred in the Republic of Uzbekistan are not determined. Establishing appropriate maintenance procedures to develop sufficient skid resistance on the pavement surface is important for minimizing skid-related incidents. Tire tread maintenance and pavement surface maintenance are the two important elements of tire-pavement interaction that must be maintained in order to provide adequate skid resistance.

The vehicle's ability to maneuver and brake effectively may be affected by skidding on pavements. In extreme circumstances, it might cause human casualties in addition to damaging pavement [7]. When there is more speed (>60 kilometer per hour) and rainfall intensity (>300 mm per hour) [8], there is increased concern for safety as it may even hydroplane. When a film of water accumulates between the tire rubber and pavement interface, causing the vehicle to lose traction and be unable to control movements such as steering, braking or acceleration [9]. In order to assess the relationship between skid resistance and pavement texture, a variety of research efforts and investigations were carried out to determine their correlation [10]. The overall result is that the values of skid resistance and friction coefficient are determined by the surface texture features, which are influenced by multiple factors (air humidity, precipitation, traffic intensity, maintenance level and type of pavements).

The conducted and the obtained results were used as a basis for further analysis of the relationship between the extensive data on pavement texture and friction quality. However, in this presented and reviewed measurement methodologies, resource-cost effectiveness and correlation of the mean texture depth (MTD), mean profile depth (MPD), British pendulum number (BPN) and coefficient of friction (FC) measurements on a 4R18 road in Uzbekistan.

2. Materials and methods

2.1 Measurement of texture.

Pavement texture parameters are measured and evaluated to determine the level of texture and how it affects road safety. Microtexture, macrotexture, and drainage characteristics of pavement surface aggregates have a significant impact on friction degree. A well-textured road pavement surface is important to reduce traffic accidents. Pavement texture is a set of microtexture, macrotexture, and megatexture that represent the variations between the pavement surface and a truly planar surface [11]. Microtexture and macrotexture ensure pavement's friction qualities (the degree of friction of the road surface to the vehicle wheel), but at the same time not causing low-frequency vibrations and shocks on the vehicle suspension. Any pavement surface (both asphalt and cement concrete) always have roughness of various sizes and shapes, from microscopic, invisible to eye and not felt while the vehicle is moving, to large ones, after passing through which the vehicle experiences shocks and vibrations. Pavement surface deformations formed due to wear and damage (cracks, ravelling, rutting, potholes) plays a significant role in occurring traffic accidents.

Pavement texture has a significant impact on tire performance. The maximum length of the texture depends on the tire size and usually does not exceed 30-100 mm. Texture, in turn, is divided into two groups: macrotexture and microtexture. Macrotexture includes textural amplitudes more than 2-3 mm in length and more than 0.2-0.3 mm in height, formed by the stone material used in construction. The size of the aggregate or surface treatment are the primary components that form up the macrotexture. If the road surface has a good macrostructure that allows water to drain away from the tires, the degree of friction depends on the velocity. Microtexture is characterized by irregularities less than 2-3 mm length and less than 0.2-0.3 mm hight. Microtexture is determined by the intrinsic texture of the material that forms the macrotexture irregularities [11]. In the wet condition of the road surface, the microtexture affects the quality of the friction when the vehicle moves at low speeds.

Macrotexture can be measured using a variety of methods, generally are divided into static (texture depth estimation known as volumetric method) and dynamic (optical measurements by using laser technology) measures [12]. Microtexture is indirectly estimated through friction coefficient and skid resistance values. The performance of surface texture is described by comparing measurement results to threshold levels specified by various standard document (ShNQ 3.06.03-2008). Regulatory document indicates the values "for the minimum limit", "for new pavements", "for pavements at the time of operation". Pavement texture has a significant role when evaluating the skid resistance characteristics of pavements, it is still the most essential factor in the tire/pavement interaction characteristics.

Experimental measurements were carried out on a 5-km section of the 4R18 road in the Syrdarya region. The distance between each experimental point is 500 meters (Figure 1).

The pavement texture was measured and evaluated by the using road surface profilometers and volumetric "sand patch test" method. The mean texture depth (MTD) was determined by the volumetric method and the mean profile depth (MPD) measured by profilometers. All measurement and evaluation process were carried out in accordance with the normative documents (GOST 33078-2014, ASTM E1845-01, ISO/CD 13473-1).

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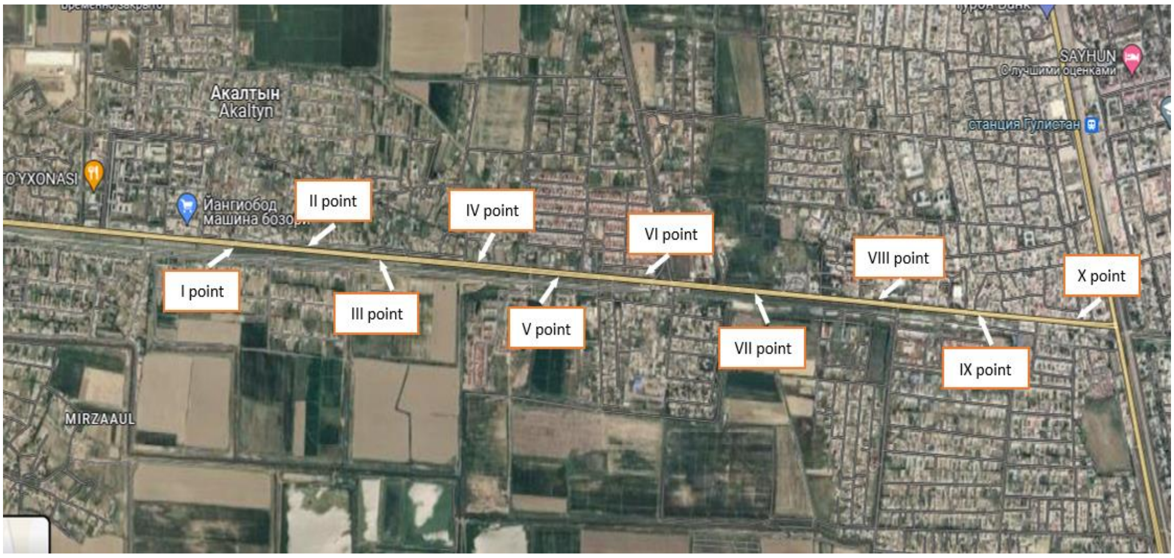

Figure 3. Location of experimental measurements

2.1.1 Measurement of texture by "Sand patch" method (Mean texture depth MTD)

Over the years, and even today, the "sand patch" method has been widely used to measure surface texture throughout the world. Although such methods are low-cost, but are often limited in terms of effectiveness during operation and influence with traffic. The method involves spreading a specific volume of granular sand material in a circular manner over a tested surface. The sand must be of the same mineral composition with a particle size of at least 0.14 mm and no more than 0.315 mm [ST RK 1279-2013]. From a measuring cylinder onto the road surface within each alignment on a surface previously cleaned with a brush, sand is poured in the form of a cone, the volume of which depends on the type of surface roughness, then distributed onto surface with a flat metal disk in the form of a spot until the lower plane of the disk begins to touch the tops of the macro-roughness protrusions and all the sand fills the depressions in the road surface (Figure 2). The volumetric method has a range of application from 0.2 mm to 8 mm MTD (mean texture depth). Measurements are carried out on road surfaces with similar asphalt pavement surfaces, where places with approximately the same surface texture are visually identified (Figure 3).

Figure 2. Texture testing assembly [source: Dorlab-ltd].

Figure 3. Pavement texture measurement process and view of a formed patch

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The texture value is taken to be the mean texture depth between the peaks and valleys of the pavement mineral aggregates. The scale on the templates is constructed using a formula that can also be used to determine the mean texture depth of texture MTD mm (1-equation) [13]:

$$MTD = 10 \times \frac{V}{F} = 10 \times \frac{4V}{\pi D^2} \quad (1)$$

Where: V is the volume of sand distributed over the rough surface, cm^3;
F is the area of the sand patch, cm^2;
D is the average diameter of the sand patch, cm.

Experiment results of "Sand patch test" method is indicated in table 1.

Table 1

Reference point	D_1	D_2	D_3	$D_{average}$	MTD
1	16,3	17,2	18,6	17,37	1,06
2	15,6	15,4	16,6	15,87	1,27
3	17,1	17,4	16,3	16,93	1,11
4	13,2	13	13,4	13,20	1,83
5	13,2	14,2	14,1	13,83	1,66
6	13,2	14,2	14,5	13,97	1,63
7	16,5	15,3	15,9	15,90	1,26
8	15,4	14,8	15,9	15,37	1,35
9	16,5	15,4	16,2	16,03	1,24
10	17,6	16,2	16,8	16,87	1,12

The use of a Sand patch test method (SPM) allowed for the quantification of mean texture depth. The minimum value of mean texture depth (MTD) according to standard for asphalt pavements is 1 mm [SHNK 3.06.03-2008]. The values obtained from ten experimental points correspond to the threshold requirements. This method suitable for evaluating the texture of newly constructed roads (defects on the road surface may affect the measurement results on the roads under operation).

2.1.2 Measurement of texture by road surface profilometer (Mean Profile Depth).

One of the modern devices used in the field of road diagnostics today is the "road profilometer" equipment. Many indicators and characteristics are measured by the road profilometer such as the transverse profile, ride number (RN), International Roughness Index (IRI), longitudinal profile as well as the macrotexture. The road profilometer device can have anywhere from one to twenty-one lasers total, however the number is always odd since there is always one in the beam's center (figure 4). The macrotexture measurements presented are consistent with accepted recommendations for "mean profile depth" (MPD) and root mean square (RMS). Both data can be provided with an accuracy of 100 mm (4 inches) and are continuously calculated [14].

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Figure 4. An overview Dynatest Road Surface Profilometer

The MPD value of the pavement is expressed by the difference in the average depth of the profile and the difference between the two base lengths 1 and 2 of the peak base levels with a total length of 100 mm [15]. The equation that can be used to calculate the mean profile depth of texture MPD (mm) is as follows:

$$MPD = \frac{(\text{peak level first}) - (\text{peak level second})}{2} - (average\ level)\ (2)$$

The measurement of mean profile depth is done in accordance with ISO/CD 13473-1, "Characterization of Pavement Texture Utilizing Surface Profiles" and ASTM E1845-01 "Standard Practice for Calculating Pavement Macrotexture Mean Profile Depth". The measured values of the macrotexture are presented in the table 2.

Table 2

Reference point	Mean Profile Depth		
	Left (μm)	Right (μm)	Average Left\Right (mm)
1	553,000	738,000	0.645
2	895.000	917.000	0.906
3	831.000	729.000	0.780
4	1740.000	1662.000	1.701
5	1544.000	1689.000	1.616
6	1423.000	1766.000	1.594
7	1332.000	1249.000	1.290
8	1350.000	1186.000	1.268
9	1116.000	1312.000	1.214
10	1091.000	1112.000	1.101

The values of MPD measured at the fourth and subsequent experimental points were found to be higher than 1mm. Currently, there is no scale for evaluating the MPD value of the texture in the current regulations of the Republic of Uzbekistan, so we calculated this indicator through the correlation of the MTD value (Figure 7). Currently, the Republic of Uzbekistan has a Dynatest Road Surface Profilometer (RSP) MPD measuring device, and a rating scale for Uzbekistan's road pavements needs to be developed. During the experimental measurements the following problems were identified:

- it may not operate as well on extremely rough surfaces, which could lead to inaccurate MPD measurements;
- environmental factors such as moisture, dusts or substances on the pavement surface can affect RSP measurements data;
- it is only effective for surface texture research and does not provide information about structural integrity of the pavement.

However, smaller road authorities with limited budgets may find it difficult to use RSP devices due to their high cost.

2.2 Measurement of friction coefficient

The friction coefficient is a non-dimensional ratio of the friction force between two bodies and the normal pressure force of these two bodies. Due to the fact that the friction coefficient φ largely determines the length of the car's braking distance. As a result of the studies performed, it was established that the coefficient φ depends on a large number of factors characterizing the design and operational parameters of the tire, the road surface and the conditions of their interaction. It was found that the coefficient values vary on dry surfaces from 0.7 to 1, on wet surfaces from 0.1 to 0.7, and on snowy and icy surfaces from 0.05 to 0.4. In order to explain the nature of the dependence of coefficient φ on various factors, it is necessary to consider the processes occurring in the contact zone of the wheel as it slides along the road surface [3]. In this research, we evaluated the friction quality of pavement by using IKSp-2M device at the point where we measured the texture. The principle of operation of the portable installation is based on simulating the process of sliding of a locked car wheel on a wet road surface shown in figure 5. A free-falling weight is used as a force-setting element in the design of a portable installation meter. The measurement was conducted using a consistent water film with a thickness of 1 mm. Measurement and assessment process will be done according to "State Standard" [IQN 05-2011]. 5 measurements were recorded at each 10-test reference points.

Figure 5. An overview of measurement process by IKSp-2M device

Of the five measurement results obtained, the two readings with the largest and smallest values (these are represented on a grey background) should be excluded [ST RK 1279-2013]. From the remaining three readings, arithmetic mean value was calculated, which is taken as the final result of the friction coefficient. The measured friction coefficients of wet pavement are presented in the table 3.

Table 3

Reference point	5 measurement results					Average friction coefficient
	N_1	N_2	N_3	N_4	N_5	
1	0,4	0,42	0,41	0,45	0,42	0,42
2	0,45	0,44	0,44	0,46	0,4	0,44
3	0,39	0,42	0,41	0,42	0,44	0,41
4	0,48	0,52	0,53	0,57	0,57	0,52
5	0,52	0,53	0,55	0,54	0,55	0,45
6	0,48	0,51	0,45	0,46	0,49	0,47
7	0,44	0,41	0,43	0,44	0,47	0,43
8	0,52	0,55	0,55	0,56	0,59	0,46
9	0,41	0,43	0,43	0,44	0,45	0,43
10	0,41	0,42	0,44	0,45	0,46	0,44

The road will be closed while the measurement is being carried out and the measurement process will be affected by weather factors.

There is also an influence of air temperature on the measurement results. When carrying out measurements at air temperatures other than 20°C, the influence of the temperature factor should be taken into account and the obtained values should be adjusted in accordance with the equation 2.

$$K = K_S + \frac{t-20}{1000}, (0 \leq t \leq 40) \qquad (2)$$

Where: K_S - friction coefficient value;

t - ambient air temperature during measurements, °C.

Measurement by using IKSp-2M device the minimum friction coefficient must be higher than 0,35 on roads under exploitation (above than 0,45 on newly built roads) according to standard. It can be seen from the above table 100 % of results higher than 0,35. Correlations of the IKSp-2M values with MPD, MTD and skid resistance are presented in the table 5.

2.3 Measurement of skid resistance

The force developed when a tire is prevented from rotating and slides along the pavement surface is termed as skid resistance [16]. A portable pendulum-type testing and measuring device is used in road laboratories to measure the skid resistance of pavement surfaces, as well as to test specially prepared crushed stone samples for abrasive wear. The skid resistance tester is also used for testing cement concrete road surfaces. The British Pendulum Tester (BPT) is a device frequently used over the world to assess the skid resistance of road surfaces. The method is based on the friction of a rubber liner (slider), attached to the pendulum head, with the surface of the road surface (or a sample of crushed stone). The instrument has a rigid swinging arm, the end of which contacts the road surface with a spring-loaded rubber slider. The contact distance of the rubber slider with the test surface is set between 123 mm and 127 mm [14]. This contact results in a reduction of the upward swing's energy.

Figure 6. An overview of measurement process by British Pendulum Tester device

British Pendulum Numbers (BPN) are a unit of measurement used to represent the amount of this upward swing. A larger pendulum angle corresponds to a greater slipperiness of the road surface. The scale ranges from 0 to 140. Measured skid resistance results presented in Table 4 [17].

Table 4

Test point	Mean readings at individual locations				B.P.N (mean)
	N1	N2	N3	N4	
1	40	40	44	44	42
2	42	44	46	52	46
3	40	42	47	51	45
4	54	55	57	58	56
5	50	54	56	56	54
6	54	55	56	59	56
7	51	53	58	62	56
8	54	57	59	62	58
9	43	43	46	48	45
10	37	41	41	45	41

Measurement by using BPT device suggested minimum skid resistance values on wet pavement conditions is 55 for high-speed roads [ShNK 3.06.03-2008]. It was found that the measured results in points 4, 6-8 correspond to the requirements of the minimum threshold value.

3. Results and discussion

Significant insight can be obtained from the investigation of data from the 4R18 highway's MTD, MPD, skid resistance, and friction coefficient assessments.

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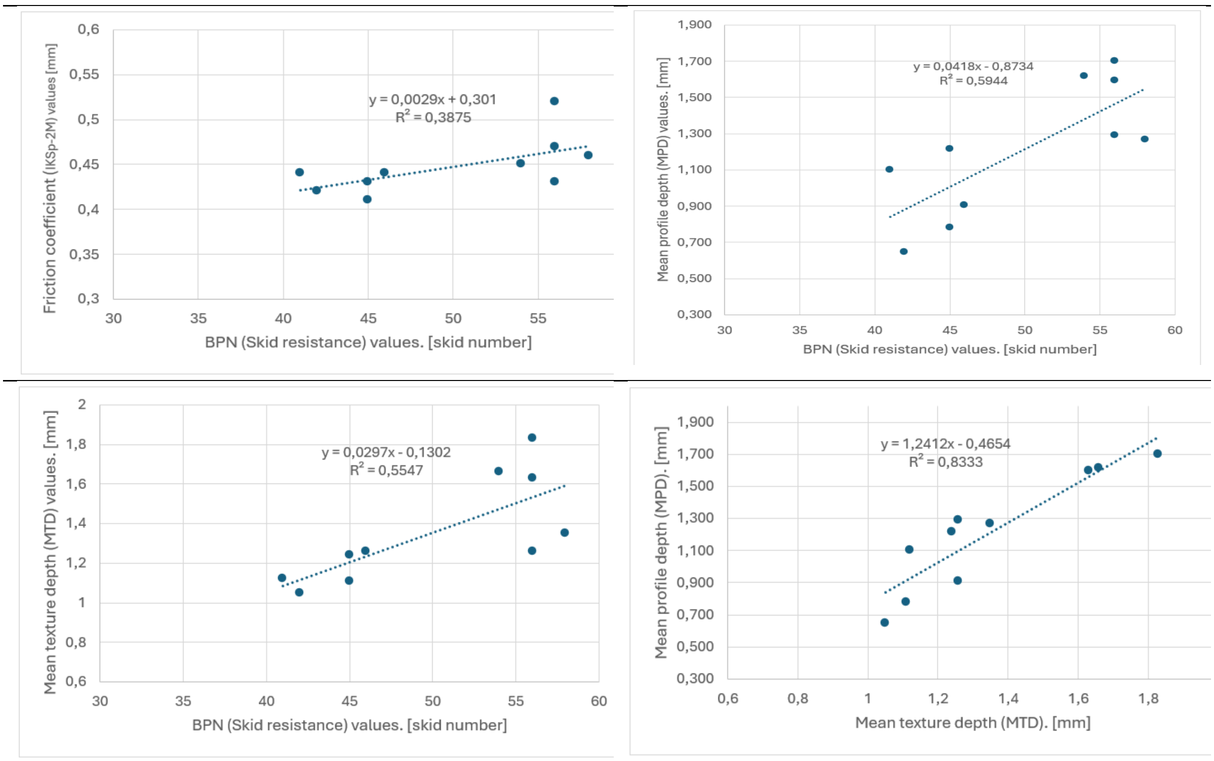
3.1. Correlation of measurement results.

Testing and evaluating different texture depth methods helps with integration once the relationships between them become clear. Statistics of regression analysis between experimental results clearly states the extent to which the results are related to each other (Table 5 and Figure 7).

Table 5

The name of the regression analysis between experimental results	Coefficient of correlation	Coefficient of R^2 determination	Adjusted R^2	Standard error
FC and SN	0,62	0,38	0,31	5,52
MPD and SN	0,77	0,59	0,54	4,5
MTD and SN	0,74	0,55	0,50	4,7
MPD and MTD	0,91	0,83	0,81	0,11
MPD and FC	0,78	0,6	0,55	0,02
MTD and FC	0,87	0,75	0,72	0,01

In this study the strongest correlation between experiments was found in the two measurements MTD and MPD, it was 0.913, and the R-square was 0.833 (meaning that 83.3% of the variance in MPD can be explained by MTD). This indicates that MPD tends to increase along with MTD and vice versa. MPD, MTD and skid resistance also had good positive correlation. Skid resistance and friction coefficient had a positive and low correlation. The R-squared value for the regression of friction coefficient and BPN is approximately 0,38 indicating that about 38,5% of the variability in friction coefficient can be explained by BPN (skid resistance). MPD, MTD and skid resistance also had good positive correlation.



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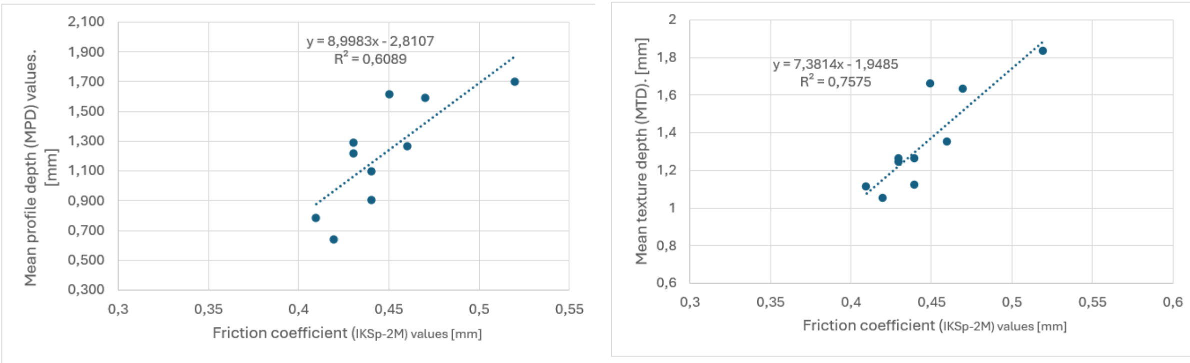

Figure 7. Linear Regression between pavement texture, skid resistance and friction coefficient.

Skid resistance and friction coefficient had a positive and low correlation. The R-squared value for the regression of friction coefficient and BPN is approximately 0,31 indicating that about 31,5% of the variability in friction coefficient can be explained by BPN (skid resistance). However, the friction coefficient showed a high correlation with MTD (0,87) and MPD (0,78).

3.2. Resource-cost effectiveness of measurement results.

The resource and economic efficiency of "Sand patch test" for MTD, Dynatest RSP device for MPD, IKSp-2M for friction coefficient, Pendelum for skid resistance measurements and evaluation is presented in the table 6 below.

Table 6

Name of the test	Type of testing measurement	Time spent on measurement and evaluation	Approximate costs
MTD by using “Sand patch test method”	field and laboratory (commonly used for short-distance road network diagnostics)	more than 3 hours	Operational cost is low
MPD by using Dynatest RSP	field and laboratory (commonly used for long-distance road network diagnostics)	10 minutes (after device setting up and calibration)	Operational cost is high
Friction coefficient by using IKSp-2M	field and laboratory (commonly used for short-distance road network diagnostics)	more than 3 hours	Operational cost is low
Skid resistance by using Pendelum Tester	field and laboratory (commonly used for short-distance road network diagnostics)	more than 3 hours	Operational cost is low

Based on the obtained results, pros and cons were analyzed:

- the sand patch test method is cheaper and more commonly used for both field and laboratory measurement. The road lane must be closed during the pavement texture measurement, and in this study the measurement process for a 5-kilometer road section takes more than 3 hours. This means that the method is not resource efficient. The 10-50 cm cubic sand used at each experimental point is not reused and is not considered good practice from an environmental point of view;

- depending on operating speed, road-weather conditions, calibration setup and survey duration this device can measure precisely MPD up to 250-350 kilometers in one working day. The device can be commonly used for long-distance road network diagnostics. Road measurement and evaluation by using this device is resource efficient but the cost of the device is very high. Operational cost is high comparing to other devices.
- the evaluation of the friction coefficient by using IKSp-2M device can be used for both field and laboratory. The low measurement speed indicates that this device is not resource-efficient when evaluating long network paths. However, this device is used in most cases to measure the coefficient of friction of road sections where traffic accidents have occurred. Operational cost is low;
- spot type of skid resistance evaluation by BPT is time-consuming, heavily influenced by environmental factors, corresponds only 50km/h speeds, provides limited insight of surface pavement (measures a very small area) it cannot be used for very long network evaluation. However, device is portable and measures the skid resistance in both wet and dry weather conditions. Operational cost is low.

Conclusion and future research

In this study, experimental spot tests were conducted on 4R18 asphalt concrete road to evaluate the correlation and regression analysis between pavement texture, skid resistance and friction coefficient. Based on the data, correlation between MTD and MPD show a strong correlation equal to R=0,91. The following MTD=0,8MPD+0,37 estimated relationship is also calculated for harmonization MTD-MPD data. Apart from this correlation between BPN skid resistance and IKSp-2M friction coefficient represented a weak correlation equal to R=0,62.

An analysis of the efficiency of use and resources of devices was conducted, and recommendations were given on choosing the best options for using devices when conducting field or laboratory research. This study also demonstrated the feasibility of estimating the pavement texture parameters, showing that it is advisable to use the RSP device, which requires less time and has higher estimation accuracy. For a developing country like Uzbekistan, the use of road profilometers with high accuracy and less time consuming compared to the “Sand patch” method in evaluating the texture of the pavement has a good effect.

It can be proposed that image processing can be used to detect between different rough surfaces, even though nominal values vary. The following targeted research will demonstrate whether photogrammetry will be precise enough to ascertain the surface's skid resistance using a non-contact method.

In our next planned research, we will analyze the dependence of road surface image on texture, friction coefficient and skid resistance.

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