IMPACT OF ROUGHNESS AND FRICTION PROPERTIES OF ROAD SURFACE OF URBAN STREETS ON THE TRAFFIC SAFETY

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Resume

Results of the study of the roughness and friction properties of the road surface of urban streets influence on the traffic safety are presented in this article. As a result of this study, an empirical dependence was obtained, reflecting the relationship between the traffic speed and a load factor under different traffic conditions; the relationship between the flow density and street capacity was also determined. The maximum permissible value of the friction coefficient for experimental streets is 0.4, and 50% of the object of study meets the requirements of operation; 50% does not. From the proposed graph of the relative dependence of pavement roughness and safety factor, it follows that the most dangerous are the streets, the pavement roughness of which is in unsatisfactory condition. To effectively solve the problem of destruction of the road surfaces, it is first of all necessary to eliminate the cause of the damage that occurs, not just its consequences.

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1 Introduction

At present, on urban streets, the intensity of vehicle traffic is increasing, while the transport and operational performance of roads are at a low level, which creates unfavorable traffic conditions and undoubtedly affects the traffic safety.

The roughness of the road surface is one of the main indicators characterizing the convenience of driving on the road and having a decisive influence on the speed of vehicles and the transport function of the road as a whole. This is a vibrational effect that is detrimental to both the car and the driver [1]. In addition, the working conditions of the driver become more difficult due to the fact that he has to constantly monitor the condition of the road, the presence of potholes and cracks on the road, slow down and increase speed and adapt to the state of transport, which often changes the trajectory of movement. Such situations force the driver to focus on maneuvers and not on other components that are important in terms of, and traffic safety. Under such conditions, an increase in number of accidents is inevitable [2].

The scope and volume of research devoted to the topic vary over a very wide range. The largest number of research works have been carried out in the field of influence of the roughness and friction properties of the road surface, as well as the road conditions, on the traffic safety. In other areas, the amount of research work is negligible.

The aim of this research was to study the impact of the roughness and friction properties of the road surface of urban streets on the traffic safety. To achieve this goal, it is necessary to solve the following research tasks: analysis of the studies performed on the topic; analysis of the current state of transport and operational indicators of the road surface for the traffic safety of urban main streets; study of the impact of road surface roughness on the traffic safety; study of the impact of friction properties of the road surface on the traffic safety. The object of research is the central streets of the cities of Tashkent (Buyuk Ipak Yuli St., Fargona Yuli St. and Izzat St.) and Chirchik (Alisher Navoi Ave., Amir Temur Ave. and Soglom Avlod St.). The subject of the study is the road surface of urban streets.

2 Literature review

The highway safety is a major priority for the public and for transportation agencies [3]. The studies of Lee, Abdel-Aty, and Nyame-Baafi [4] developed four different safety performance functions to evaluate the impact of road roughness, as measured by the International Roughness Index (IRI), on crashes using interstate highway data from five US states representing different geographic and weather regions: Arizona, Colorado. , Florida, Maryland and Michigan. The modeling results identify many significant variables, including the traffic volume and proportion of trucks, through lane count, shoulder type, median width, high-occupancy vehicle (HOV) lane operation and HOV lane count, speed limit, area type and IRI-related factors. The results indicate that increased IRI contributes to large numbers of total crashes.

The condition assessment of pavement has a predominant role in delivering safety and comfort to users. Roughness is considered the most important characteristics as it affects the road safety and vehicle operating costs. Authorities spend a significant quantity of resources on using conventional methods for measuring roughness. Many studies are performed to estimate roughness by deploying smartphone sensors. However, no consideration is given to influence of the speed of the host vehicle in roughness evaluation using smartphones. Results of the smartphone-based pavement roughness estimation experiment showed a high correlation value of 0.73 and proved the accuracy of the method [5].

The influence of the road surfaces' roughness on the conditions for the movement of mixed flows was studied by Azizov [6]. According to the results of the author's research, the assessment of the roughness of the pavement, along the track of the car and along the edge of the carriageway shows that in all the cases the roughness of the pavement is worse at the edge of the carriageway than in the middle part; vibrations of tractor trailers increase with deterioration of the pavement (Figure 1).

The work of Eshkabilov and Yunusov [7] presents experimental studies based on the road profile measurements using accelerometers and the international roughness index (IRI) assessment tools and practical recommendations regarding the processing of measured acceleration data, from the point of view of a digital filter plan and the transformation of vertical data accelerations into displacement data. The capabilities of various applications used to measure the roughness of the road surface using smartphones, as well as the possibilities, advantages and disadvantages of creating a road database in the conditions of Uzbekistan, were studied in the work of Urokov and Soataliev [8].

The issues of assessing the conditions for the occurrence of a dangerous traffic situation due to a decrease in the traffic safety on uneven road surfaces were considered by Filippov, Smirnova, and Kiyashko [9]. It is proposed to introduce a partial accident rate that takes into account the roughness of the coatings into the methodology of the accident rate.

The factors that determine the force of friction (adhesion) in the contact of automobile tires with the pavement of the roadway are considered in the works of Nemchinov [10]. The role of the surface roughness of road surfaces in formation of the friction force is noted. An assessment is given to devices for assessing the adhesion qualities of the road surfaces.

Changes in the value of the adhesion coefficient under the influence of various factors are considered in the works of Evtyukov and Evtyukov [11]. The dependence of the adhesion coefficient on the state of the type of road surface and on the speed of the car for surfaces with different roughness is presented in detail. The indicators of reliability of the contact of a car tire with the road surface are presented, as well.

Specifically, Uzbekistan researchers had been working on evaluation of the impact of uneven road surfaces on traffic safety and development of the network of urban roads and streets by using experience of researchers from other countries in urban street management systems [12-13]. The Canadian scientists

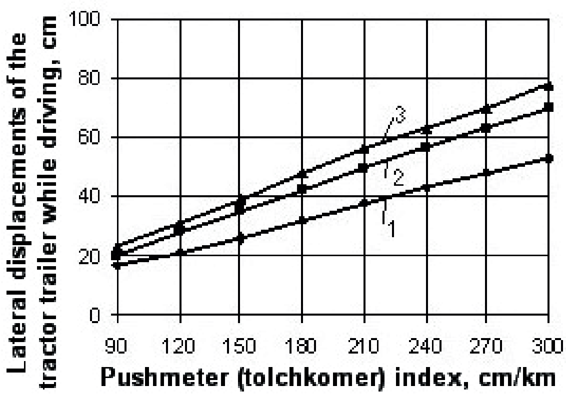

Figure 1 *Lateral vibrations of the tractor train depending on the condition of the coating: 1 - tractor trains consisting of 1 trailer; 2 - tractor trains consisting of 3 trailers; 3 - tractor trains consisting of 5 trailers*

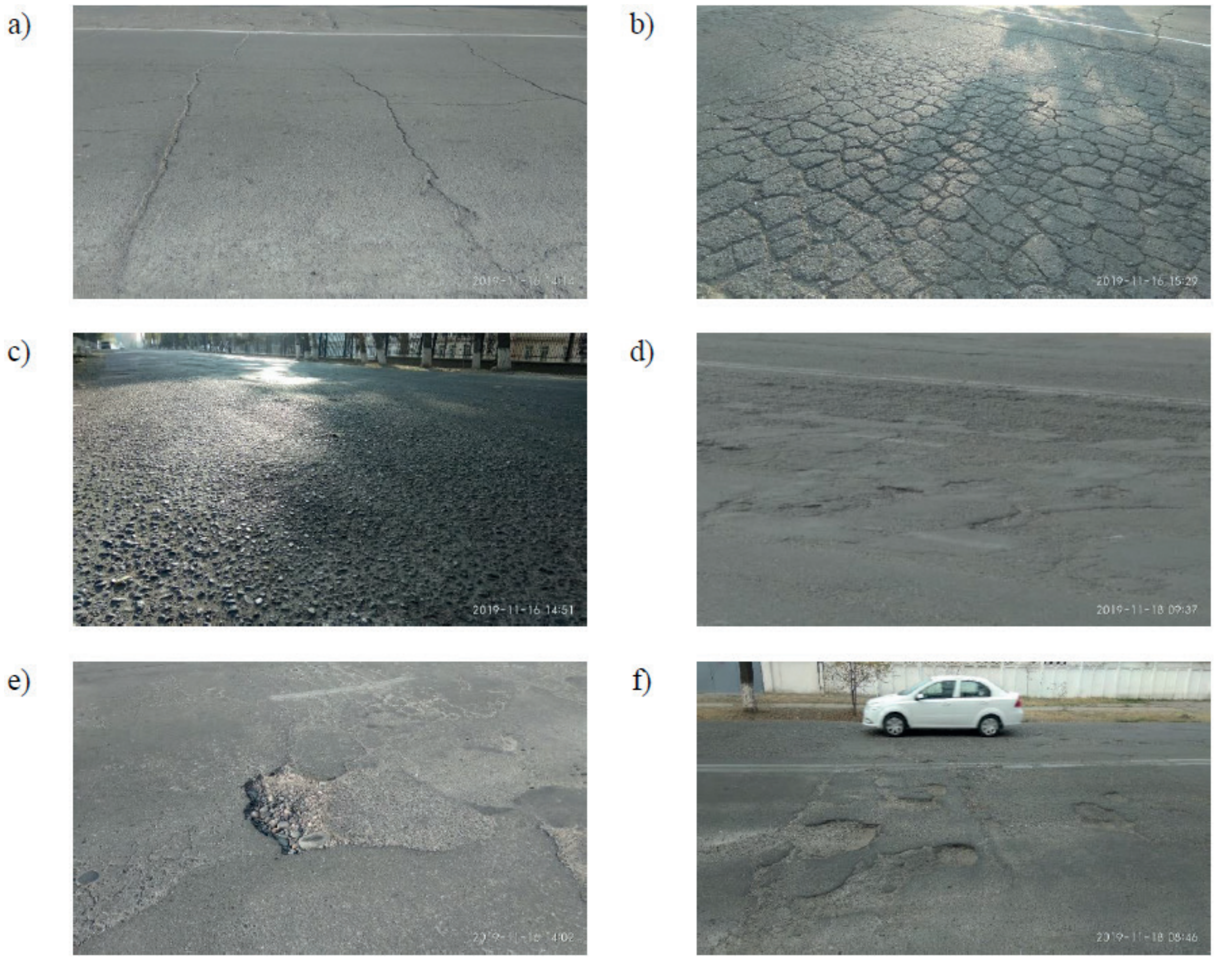

***Figure 2** Various defects on the pavement of the object of study: a) transverse cracks on PK 6+00 Amir Temur Ave., Chirchik; b) a grid of cracks at PK 8+50 Soglom Avlod St., Chirchik; c) peeling at PK 46+50 Amir Temur Ave., Chirchik; d) chipping at PK 59+00 Fargona Yuli St., Tashkent; e) potholes at PK 3+25 Amir Temur Ave., Chirchik; f) pitting at PK 3+25 Izzat St., Tashkent*

[14-19] have had valuable results on their explorations that are associated with analysis of influences on as-built pavement roughness in asphalt overlays at long-term pavement performance test sites, as well as determining the road surface and weather conditions that have a significant impact on the traffic stream characteristics. On the other hand, effects of vehicular speed on assessment of the pavement road roughness have been studied by other researchers [20-24]. As a result, the topic continues to be authentic by influencing its effect on other case studies.

Based on the review of previous studies, it was determined that the scope and volume of research works devoted to the "study of the impact of roughness and friction properties of road surfaces of urban streets on traffic safety" vary widely.

3 Methodology

The road surface is the uppermost part of the pavement, which is directly affected by the wheels of cars and weather and climatic factors. Destruction can be caused by: low quality of work; insufficient or incorrect consideration of hydrogeological conditions; and the use of low-quality materials. Of great importance in ensuring the stability of road pavement is the timely repair of destroyed sections of the road surface. The appearance of residual (irreversible) deformations that are not eliminated in a timely manner leads to significant damage, both under the influence of vehicle traffic and under the influence of weather and climatic factors. The loss of pavement roughness is caused by the continuous impact of car wheels and natural and climatic factors. The loss of roughness is greatly influenced by errors made in the design, construction and maintenance of pavements [25].

Currently, on the streets of the cities of Uzbekistan, the intensity of vehicle traffic is increasing and the transport and operational indicators of roads are at a low level. This creates unfavorable conditions for the movement of vehicles and undoubtedly affects the traffic safety. Additionally, a huge variety of road defects can cause serious accidents. Basically, such defects include pitting, rutting, breaks, potholes, waves, chipping, peeling, a network of cracks, transverse cracks, etc.

Table 1 *Unified form of statements of defects of the object of study*

Object of study	Road surface defects									
	Transverse cracks (m²)	Grid of cracks (m²)	Peeling (m²)	Chipping (m²)	Waves (m²)	Potholes (m²)	Pitting (m²)	Total pavement area with defects (m²)	Total pavement area (m²)	Percentage of defect area (%)
Buyuk Ipak Yuli St., Tashkent	43	8149	1821	2848	820	498	50	14229	102900	13.8
Fargona Yuli St., Tashkent	63	7103	12760	5916	498	648	1400	28388	142800	19.9
Izzat St., Tashkent	28	1480	1858	875	0	883	1750	6874	24500	28
Alisher Navoi Ave., Chirchik	134	1310	3721	0	0	0	0	5165	117600	4.4
Amir Temur Ave., Chirchik	51	7305	2535	820	500	700	150	12061	62300	19.4
Soglom Avlod St., Chirchik	26	3070	940	3720	0	590	0	8346	32200	25.9

Asphalt and concrete pavements are very convenient for vehicle traffic. Despite its good technological and operational properties, such a coating is sensitive to changes in temperature and humidity: the binder material contained in the coating becomes obsolete over time and the strength and deformation properties change [26].

To analyze the current state of the object of study, which identified the streets of the cities of Tashkent (Buyuk Ipak Yuli St., Fargona Yuli St. and Izzat St.) and Chirchik (Alisher Navoi Ave., Amir Temur Ave. and Soglom Avlod St.), visual inspections and measurement work were carried out, and photographs of various pavement defects were taken (Figure 2):

A visual assessment of the condition of the road surface allows obtaining data on its condition, identifying places that are subject to assessment of the strength of the pavement and determining the amount of damage necessary for planning repairs and maintenance [27].

The destruction of asphalt concrete pavements occurs as a result of the complex impact of such factors as: miscalculations in the design of a highway, the use of outdated technologies and low-quality materials in the construction of a road, violations of technologies and rules for the road construction, adverse weather conditions and an increase in traffic loads.

In the process of data collection, lists of defects of the object of study were compiled and experimental sites were identified for conducting the planned experiments of the study. Below is a unified form of statements of defects of the object of study (Table 1):

From Table 1, it can be seen that on almost all the streets of the object of study, there are many different defects in the pavement, including potholes and pitting and their distribution occupies a considerable area. So, the most common type of defect, in terms of the area of the road surface, is a network of cracks, which was formed during the further development of individual cracks over time. In addition, the further development of the network of cracks can lead to more serious types of defects, such as potholes, chipping, breaks, peeling, pitting, etc. This condition of the road surface affects the modes of movement of vehicles, their speed and trajectory and may even cause accidents.

4 Results and discussion

4.1 Study of the impact of roughness of the road surface of urban streets on the traffic safety

The roughness of the road surface is one of the main indicators characterizing the convenience of driving on a highway and having a decisive influence on the speed and safety of traffic [25]. During the maintenance of roads, the roughness of the road surface deteriorates due to its damage and deformation under the influence of traffic loads and weather conditions.

The effect of pavement roughness on the transport and operational qualities of roads has been studied to a much greater extent than its effect on the traffic safety. Uneven road surfaces can cause the driver to lose control of the vehicle. At the same time, accidents, such as a collision of cars in a traffic stream, occur, as a rule, when braking in front of a car due to its entry into an uneven area. The same accidents occur when

***Table 2** Evaluation of pavement roughness in experimental streets*

Street name	Number of gaps under the rail (%)				Roughness condition
	less than 3 mm	3-5 mm	more than 5 mm	the biggest	
Alisher Navoi Ave., Chirchik (PK 29+00 - PK 34+00)	96	3	1	6 mm	Excellent
Buyuk Ipak Yuli St., Tashkent (PK 3+00 - PK 8+00)	91	7	2	7 mm	Good
Soglom Avlod St., Chirchik (PK 5+00 - PK 10+00)	82	13	5	9 mm	Satisfactory
Amir Temur Ave., Chirchik (PK 45+00 - PK 50+00)	81	14	5	10 mm	Satisfactory
Fargona Yuli St., Tashkent (PK 54+00 - PK 59+00)	39	47	14	12 mm	Unsatisfactory
Izzat St., Tashkent (PK 15+00 - PK 20+00)	41	44	15	13 mm	Unsatisfactory

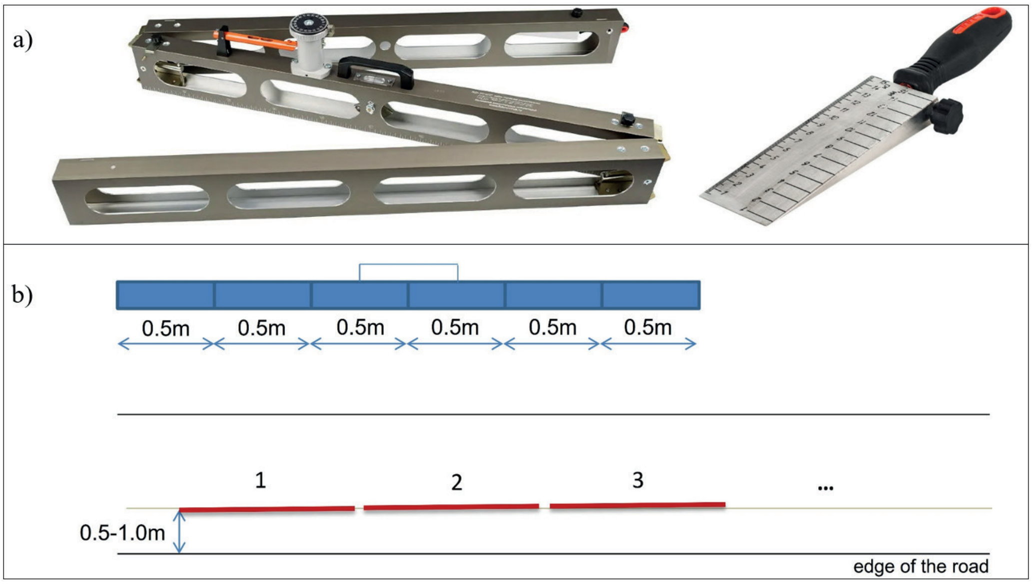

***Figure 3** Technical specifications of the instrument in pavement roughness measurements: a) a three-meter rail and a wedge gauge; b) measurement site*

a car enters the oncoming lane to avoid bumps in its own lane. The condition of the pavement of the carriageway of roads in terms of longitudinal roughness is assessed by comparing the actual roughness indicators with the minimum allowable ones. The road surface satisfies the required operating conditions for roughness if the value of the actual roughness index is less than the minimum allowable value or equal to this value [28].

To study the effect of the road surface roughness on the traffic safety, the surface roughness was measured on all the experimental sections of streets with a three-meter rail (Table 2) and its condition was assessed according to the regulatory requirements of IKN 05-2011 and MSHN 25-2005 [27, 29]. Technical specifications of the instrument in pavement roughness measurements are shown in Figure 3.

It is known that the main indicator that determines the target function of roads and urban streets is the speed of movement. This indicator is influenced by many factors, some of which are: the intensity and composition of the traffic flow; the width of the carriageway and the number of lanes in each direction; the flux density; the density of the road network; the level of traffic organization; visibility conditions, etc.

Development of engineering measures for organization of traffic is possible only if there is information characterizing the traffic flows in which the movement occurs. Based on the traffic research and the practice of its organization, numerous meters have been developed that characterize the movement of the traffic flow. The primary indicators include the total intensity and composition of the traffic flow over a relatively long period of time.

The intensity of traffic and the composition of the traffic flow of the object of study are shown in Figures 4-5.

Based on observations of the composition of the traffic flow on the experimental streets, a tendency for a high proportion of cars has been established. Figure 5 shows the composition of the traffic flow in the form of a cyclogram, reflecting the ratio of cars by type to the total number.

Roughness has a great influence on the traffic speed. The influence of roughness on the maximum

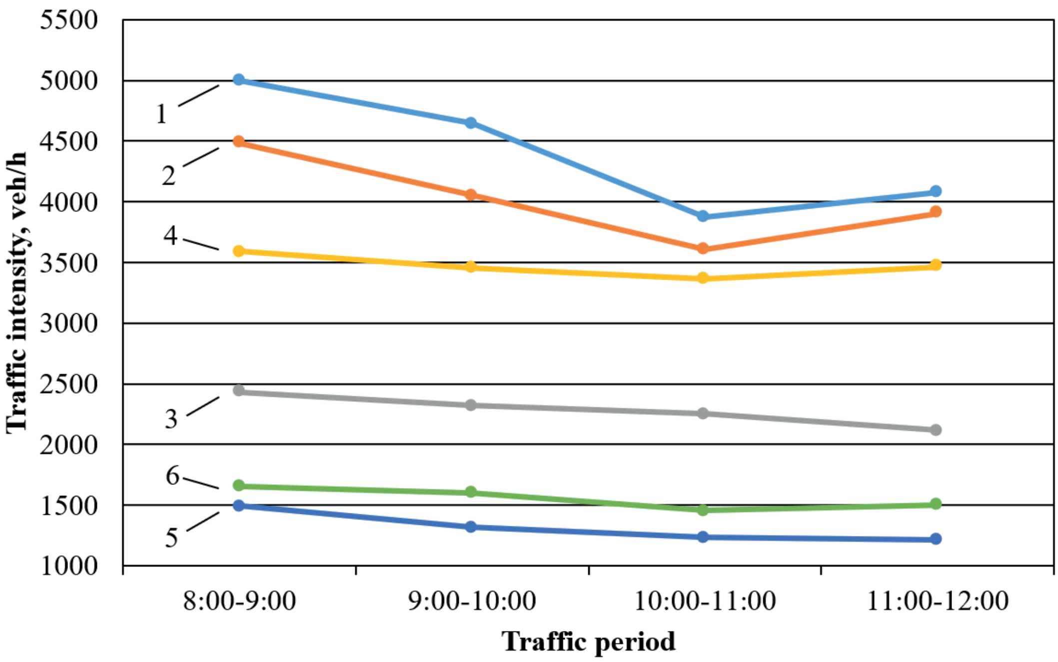

Figure 4 *Traffic intensity at the object of study: 1 - Buyuk Ipak Yuli St. (Tashkent); 2 - Fargona Yuli St. (Tashkent); 3 - Izzat St. (Tashkent); 4 - Alisher Navoi Ave. (Chirchik); 5 - Amir Temur Ave. (Chirchik); 6 - Soglom Avlod St. (Chirchik)*

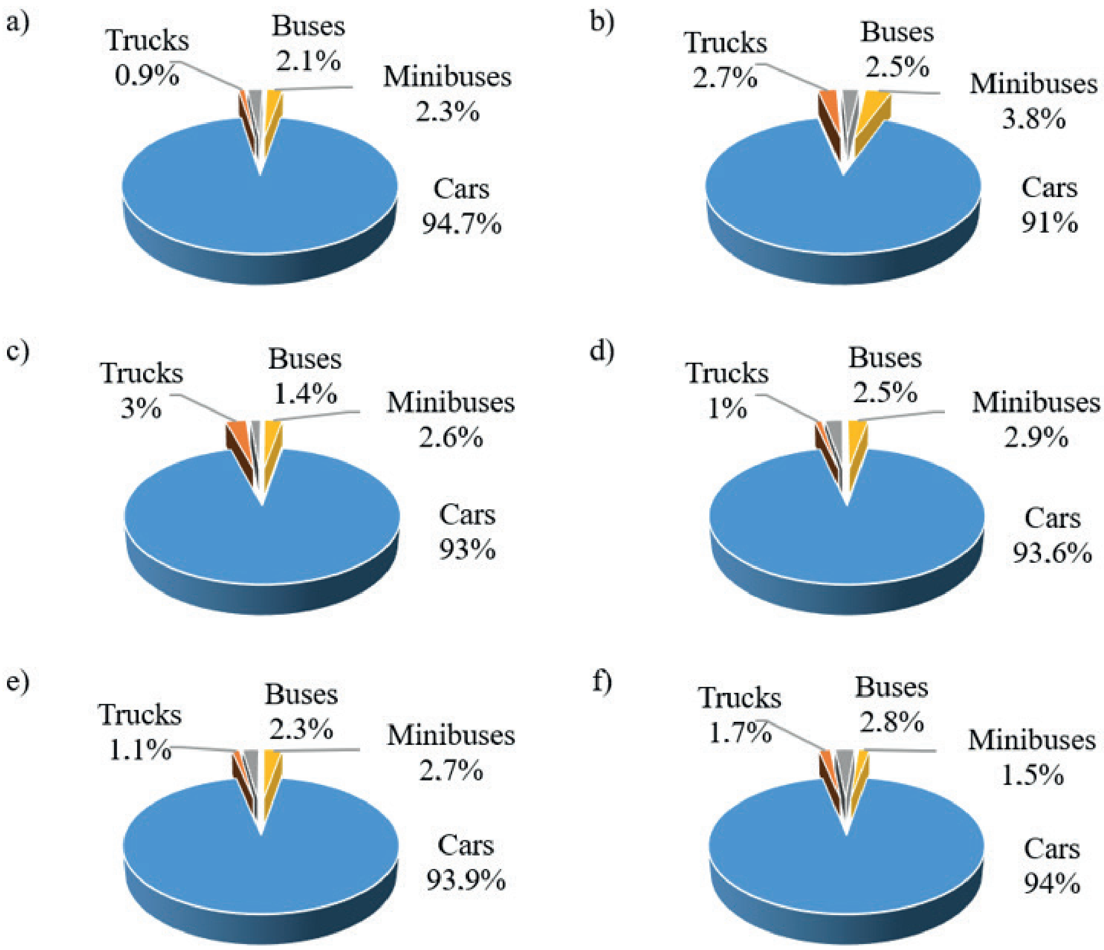

Figure 5 *The composition of the traffic flow at the object of study: a) Buyuk Ipak Yuli St. (Tashkent); b) Fargona Yuli St. (Tashkent); c) Izzat St. (Tashkent); d) Alisher Navoi Ave. (Chirchik); e) Amir Temur Ave. (Chirchik); f) Soglom Avlod St. (Chirchik)*

speed is determined in the case of measuring roughness, by setting the PKRS (Device to Control Roughness and Adhesion) according to the formula of Vasilyev [30]:

$$V_{\max} = 7500/\sqrt{S_c} + 0.15\, S_c,\, km/h\,, \quad (1)$$

where: S_c - pavement roughness, cm/km.

When measuring the roughness with the pushmeter (tolchkomer), the maximum speed is determined by the formula of Sidenko [30]:

$$V_{\max} = 850/\sqrt{S_c},\, km/h\,, \quad (2)$$

where: S_c - pavement roughness, cm/km.

According to Silyanov and Domke [25], as the roughness deteriorates, the speed of cars of all types decreases (Figure 6).

The measured and evaluated state of roughness on the experimental streets indirectly affects the speed of movement and, therefore, the speed of movement along these streets, which have the same design speed, was also measured. The street section was chosen to measure the speed of cars with a stopwatch; the measurement distance was 50 m and the number of vehicles was 120. The first step in the processing of observational data is the compilation of a summary. To compile a summary, all velocities obtained as a result of observations are combined into numbers. The results of experimental measurements and estimates are given in Table 3.

When developing mathematical statistics, modal and cumulative speed curves along the experimental streets were constructed using field measurements of speed (Figure 7).

With help of the cumulative curve, the values of

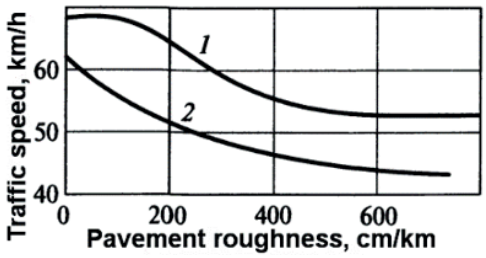

Figure 6 *Impact of pavement roughness on speed according to Silyanov and Domke: 1 - cars; 2 - trucks [25]*

Table 3 *Example of digits and summary of vehicle speeds*

Pavement roughness condition	Speed value 15, 50, 85, 95% security				
	V_m	V_{15}	V_{50}	V_{85}	V_{95}
Excellent	67	51	57	68	70
Good	61	47	60	67	69
Satisfactorily	55	41	51	57	59
Unsatisfactorily	35	30	35	39	45

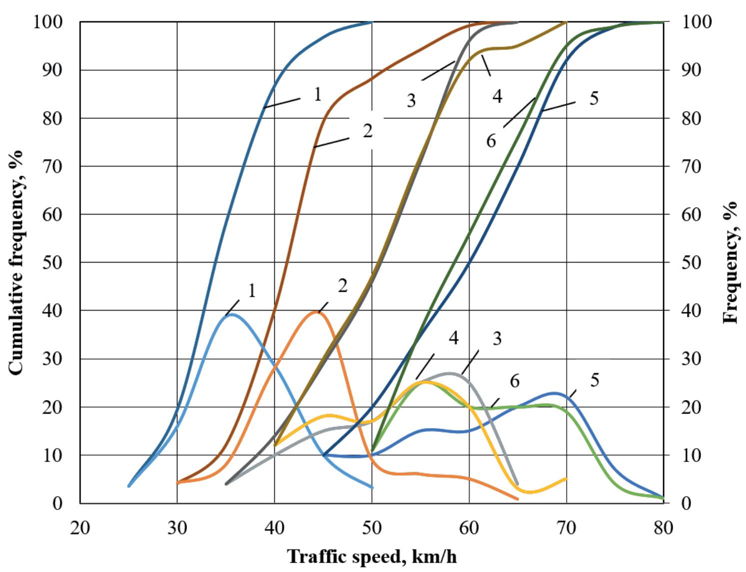

Figure 7 *Modal and cumulative speed curves: 1 - Izzat St., Tashkent; 2 - Fargona Yuli St., Tashkent; 3 - Amir Temur Ave., Chirchik; 4 - Soglom Avlod St., Chirchik; 5 - Buyuk Ipak Yuli St., Tashkent; 6 - Alisher Navoi Ave., Chirchik*

the speeds corresponding to 15, 50, 85 and 95% of the security are determined. The speed values of 15% security show the speed of cars that are overtaken by the remaining 85% of cars. These 15% of cars are usually the source of accidents. Therefore, with artificial regulation of traffic, it is advisable to take this speed as the minimum allowable. The values of modal speed (V_m) occur often in the sample of spot speed in the given data [31].

Traffic hazards were assessed using a safety factor and the results were statistically analyzed. Safety coefficients are the ratios of the maximum speed of movement on the site to the maximum speed of entry of cars into this section:

$$F_S = V_S / V_{en}\,, \tag{3}$$

where: V_s - the maximum speed of movement on the site, km/h;
V_{en} - the maximum speed of entry into this section, km/h.

The safety factor method takes into account the movement of a single vehicle, which is a good measure for safety and typical for traffic conditions on roads with low intensity or hours of slowdown in traffic on busier roads. This does not prevent its use for all the types of roads since overtaking is practically excluded at high traffic intensity and the calculation for a single car is directed towards a safety margin.

Sections with safety factors less than 0.8 are unacceptable in new road projects. In reconstruction and overhaul projects, safety factors are taken into account according to MSHN 25-2005 [29].

To assess the safety factors, sections were allocated at a distance of 100 meters from all experimental streets and the maximum speed of an individual car on these streets was determined using a stopwatch. It was found that the street safety factor changes with the speed and roughness of the pavement (Table 4).

Table 4 shows that when vehicles pass from the excellent condition to the unsatisfied condition, the safety index is $F_s < 1$, which means that the condition of the pavement is uneven. If the safety index is $F_s = 1$, it means that the condition of the pavement is uniform in this section. It would seem that by forcing drivers to slow down, uneven pavements should reduce the number of accidents. However, the analysis of the road traffic accidents often shows that they often focus on areas whose geometric characteristics and longitudinal profile are quite favorable, where after areas with even coverage there are areas with uneven coverage.

4.2 Study of the impact of the friction properties of the road surface of urban streets on traffic safety

The friction properties of the road surface are one of the important transport and operational indicators of highways and urban streets. It shows the reliability of the contact of a car tire with the road surface and, in many cases, affects the traffic safety. The poor condition of the friction properties significantly worsens driving conditions, causing vibrations that are harmful to the driver and vehicles and significantly complicating the working conditions of drivers. With significant fluctuations, the tire can also be detached from the pavement surface, resulting in a complete loss of controllability and stability, which at high speed can lead to a dangerous traffic situation and an accident. The condition of road surfaces in terms of friction is assessed by comparing the actual value of the coefficient of longitudinal adhesion with its minimum allowable

Table 4 *Changes in safety factor depending on roughness condition*

Roughness condition	Safety factor values, F_S			
excellent	1			
good	0.9	1		
satisfactorily	0.75	0.8	1	
unsatisfactorily	0.55	0.6	0.75	1

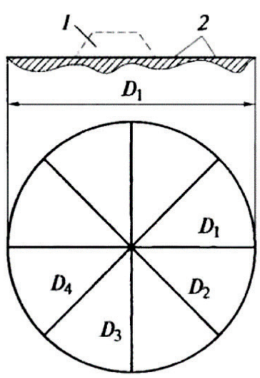

Figure 8 *"Sand spot" method: 1 - a hill of sand before leveling; 2 - sand after leveling*

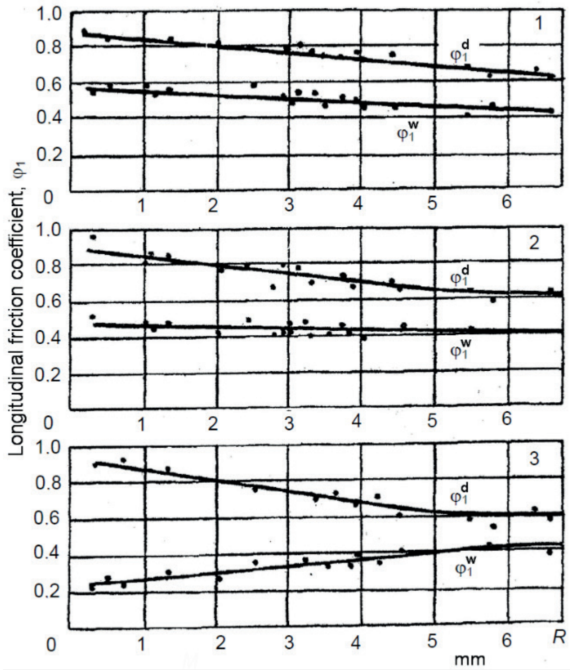

Figure 9 *Dependence of the adhesion coefficient on the macroroughness of the road surface. Tire 6.45-13 R with a new tread pattern.* φ_d, φ_w *- coefficient of longitudinal adhesion, on a dry and wet rough wear layer, respectively. Traffic speed, km/h: 1 - 40 km/h; 2 - 60 km/h; 3 - 80 km/h [33]*

value. The road surface meets the requirements for operation if the actual value of the friction coefficient is greater than or equal to the minimum allowable value. The minimum allowable friction coefficient is 0.3 when measured with a tire without a tread pattern and 0.4 when measured with a tire with a tread pattern [32].

The "sand spot" method is a set of equipment that includes a measuring container of a volume of at least 20 cm^3, a flat disk (stamp) of a diameter of 10 cm for distributing sand, a measuring ruler of a length of at least 30 cm and a sweeping brush. Measurements require clean, fine (particle size no more than 0.2-0.3 mm) natural sand in an air-dry state, gypsum or quick-hardening cement and water. When taking measurements, a certain volume of sand (20-50 cm^3) is poured onto the surface of the coating and, using a stamp, it is evenly distributed flush with the surface of the friction properties protrusions, giving the sand spot the shape of a circle, rectangle, or square (Figure 8) [28].

Then the diameter of the circle is measured in four mutually perpendicular directions (D_1 - D_2) and the arithmetic mean diameter is calculated, by which the average depth of the friction property depressions is determined:

$$\Delta_{av} = 4V_n/\pi D^2 , \quad (4)$$

where: V_n - sand volume, cm^3;
D - average circle diameter, cm.

If it is necessary to determine the height of the protrusions, the surface occupied by sand is contoured, the sand is removed from the depressions of macroroughness with a brush and the cleaned surface of the coating is lubricated with technical glycerin. Then, an impression is taken from the coating: a liquid dough is made from gypsum, quick-hardening cement, or other similar material and is distributed over the surface under study with a layer of 1.0-1.5 cm. After 5-7 minutes, the impression is separated from the coatings and held for 10-15 minutes until it hardened. After that, the volume of friction property depressions is determined (numerically equal to the volume of friction property protrusions) using the "sand spot" method and the average height of the protrusions is calculated [28].

As a result of Nemchinov's proposal of the dependence of the friction (adhesion) coefficient on the contact of automobile tires with the pavement of the roadway, it was found that on the wet pavements at low speeds, with an increase in friction properties, the adhesion coefficient decreases and with an increase in speed, it first stabilizes and then even increases with an increase in the average height of the protrusions up to 5.5 mm (Figure 9) [33].

To study the effect of road surface friction properties on traffic safety, the pavement friction properties were measured at every 1000 m of all the experimental streets using the "sand spot" method and their condition was evaluated using the method proposed by Nemchinov and according to the regulatory requirements of IKN 05-2011 and MSHN 25-2005 [27, 29]. The condition of the road surfaces in terms of friction is assessed by comparing the actual value of the coefficient of longitudinal adhesion with its minimum allowable value (Table 5).

***Table 5** Evaluation of pavement friction properties of experimental streets*

Street name	Measurement site	Δ_{av}, cm	φ_w	The state of friction properties according to the requirements of operation
Buyuk Ipak Yuli St., Tashkent	PK 10+00	0.4	0.5	satisfies
	PK 20+00	0.65	0.42	satisfies
	PK 30+00	0.88	0.26	does not satisfy
	PK 40+00	0.9	0.25	does not satisfy
	PK 50+00	0.74	0.35	does not satisfy
	PK 60+00	0.44	0.48	satisfies
Fargona Yuli St., Tashkent	PK 10+00	0.52	0.45	satisfies
	PK 20+00	0.86	0.34	does not satisfy
	PK 30+00	0.5	0.45	satisfies
	PK 40+00	0.77	0.35	does not satisfy
	PK 50+00	0.89	0.25	does not satisfy
	PK 60+00	0.74	0.35	does not satisfy
Izzat St., Tashkent	PK 10+00	0.63	0.42	satisfies
	PK 20+00	0.82	0.32	does not satisfy
Alisher Navoi Ave., Chirchik	PK 10+00	0.52	0.45	satisfies
	PK 20+00	0.55	0.44	satisfies
	PK 30+00	0.7	0.38	does not satisfy
	PK 40+00	0.65	0.42	satisfies
	PK 50+00	0.89	0.25	does not satisfy
	PK 60+00	0.36	0.5	satisfies
	PK 70+00	0.5	0.45	satisfies
Amir Temur Ave., Chirchik	PK 10+00	0.82	0.32	does not satisfy
	PK 20+00	0.88	0.26	does not satisfy
	PK 30+00	0.75	0.35	does not satisfy
	PK 40+00	0.75	0.35	does not satisfy
	PK 50+00	0.33	0.5	satisfies
Soglom Avlod St., Chirchik	PK 10+00	0.7	0.38	does not satisfy
	PK 20+00	0.8	0.3	does not satisfy

The road surface meets the requirements for operation if the actual value of the friction coefficient is greater than or equal to the minimum allowable value. The maximum permissible value of the friction coefficient is 0.3 when measured by a tire without a tread pattern and 0.4 when measured by a tire with a tread pattern [27].

The measured and estimated friction properties of the experimental streets indirectly affect the speed of movement and therefore, the speed of movement along these streets was also measured. This indicator is also influenced by the level of traffic congestion on the road. When processing the data, a graph was constructed of dependence of the speed of the traffic flow on the value of the load factor (Figure 10), from which it follows that in the interval $0 \leq z \leq 0.2$, the traffic flow moves at a speed of 55 to 70 km/h; in the interval $0.2 \leq z \leq 0.45$ - from 35 to 55 km/h,; in the interval $0.45 \leq z \leq 0.7$ - from 20 to 45 km/h,; and in the interval $0.7 \leq z \leq 1$ traffic speed is less than 20 km/h.

According to results of the study of the traffic flow conditions on the experimental streets, the relationship between the flow density and street capacity was determined (Figure 11).

From any of the graphs shown in Figure 11, it can be clearly seen how the throughput of the street changes depending on the flow density and that with an increase in the flow density, the throughput of the street decreases. Additionally, on some streets (Izzat St., Tashkent; Soglom Avlod St., Chirchik), the indicators are low due to the fact that the geometric parameters and road conditions are in an inappropriate condition.

5 Conclusions

Based on the review of previous studies, it was determined that the scope and volume of research works devoted to the «study of the impact of roughness and friction properties of road surfaces of urban streets on traffic safety» vary widely. It was determined that on almost all the streets of the object of study there are many

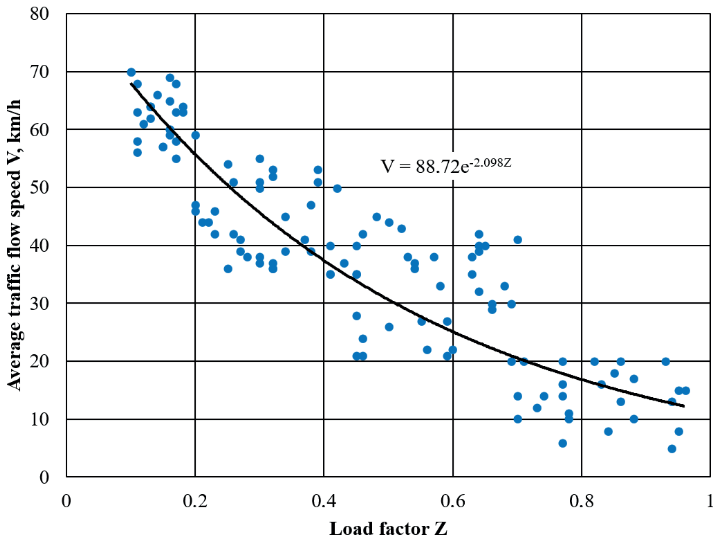

***Figure 10** A graph of the relationship between the traffic speed and a load factor under different traffic conditions*

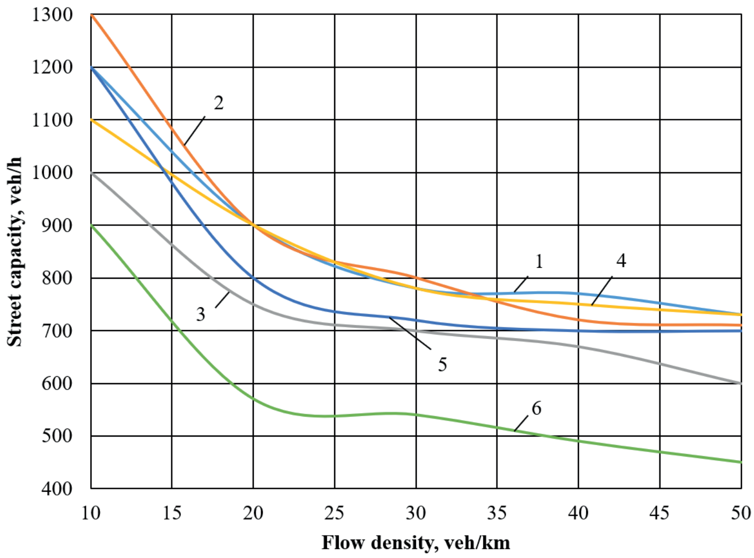

***Figure 11** A graph of the relationship between the flow density and a street capacity: 1 - Buyuk Ipak Yuli St. (Tashkent); 2 - Fargona Yuli St. (Tashkent); 3 - Izzat St. (Tashkent); 4 - Alisher Navoi Ave. (Chirchik); 5 - Amir Temur Ave. (Chirchik); 6 - Soglom Avlod St. (Chirchik)*

different defects in the pavement, including potholes and pitting and their distribution occupies a considerable area.

To study the influence of the roughness and friction properties of the road surface on the traffic safety, the relative dependence of pavement roughness and safety factor was proposed; an empirical dependence was obtained, reflecting the relationship between the traffic speed and a load factor, under different traffic conditions; and the relationship between the flow density and a street capacity was determined. The maximum permissible value of the friction coefficient for experimental streets is 0.4 and 50% of the object of study meets the requirements of operation; 50% does not. From the proposed graph of the relative dependence of the pavement roughness and a safety factor, it follows that the most dangerous ($F_s < 0.6$) are the Fargona Yuli and Izzat streets of the city of Tashkent, the pavement roughness of which is in unsatisfactory condition. The measured and estimated friction properties of the experimental streets indirectly affect the speed of movement and, therefore, the speed of movement along these streets was also measured. This indicator is also influenced by the level of traffic congestion on the road. From the proposed graph of the relationship between the flow density and a street capacity, it can be seen that as the flow density increases, the street capacity decreases.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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