International Journal Of Engineering Research And Development
e- ISSN: 2278-067X, p-ISSN: 2278-800X, www.ijerd.com
Volume 15, Issue 1 (January 2019), PP.41-54

Assessment of Surface Friction Characteristics for Egyptian Highways

Ahmed M. Abdallah[1], Ahmed E. Abu Elmaaty[2], Mohamed G. Alzoghby[3]
[1]Construction Engineering and Utilities Department, Zagazig University
[2]Civil Engineering Department, Menoufia University
[3]Civil Engineering Department, Canadian International College
Corresponding Author: Ahmed M. Abdallah

ABSTRACT :*Frictional properties of road surface play a major role in road safety; as the friction between tire and pavement is considered an essential contributing factor in reducing potential crashes. Due to the increase in the percentage of traffic accident rates in Egypt; the assessment of friction values of the surface layer became one of the main problems which needed to be studied. This paper presents the evaluation of pavement friction values for major types of Egyptian roads; desert, agriculture, and urban roads. In this study, tested roads have been evaluated by a portable skid resistance mechanism using a British Pendulum (B.P.) tester according to the American Society for Testing and Materials (ASTM E303-93).*

The field tests were performed within the same region during an equivalent summer temperature. The surface skid resistance is anticipated at its low value because of asphalt high viscosity according to a high temperature to control test conditions that led to minimizing variability in test results.

Relations between friction values and Cumulative Traffic (C.T.), surface layer ages and accident rates have been developed for evaluating roads. According to the regression analysis for friction and other parameters, it can be concluded that surface friction value is highly affected by road ages and C.T.

Date of Submission: 25-02-2019 Date of acceptance: 18-03-2019

I. INTRODUCTION

The accident rates increase extremely in Egypt; as it is considered one of the highest countries in the world with accident rate. It's estimated that 22,793 road traffic accidents occur each year, resulting in 35,718 injuries. Fatality rates over the last years have also averaged 6,486 based on police-reported accidents [1]. Recently, it was reported that Egypt could be losing up to 6 billion LE per year through a road traffic accident. Traffic accidents are one of the most serious negative impacts of road traffic on society. Traffic accidents cause a very significant economic loss at both the national and international levels [2]. Skid resistance (SR) is an essential pavement evaluation parameter. SR is a major factor in traffic safety because it is the force that provides the grip that a tire needs to maintain vehicle under control and for stopping in emergency situations. Inadequate SR will lead to higher incidences of skid related accidents [3].

The main objective of this study is to investigate the relationships between friction values and other factors which affect on frictional values based on the recent studies which indicated that the most frictional related factors including cumulative traffic (C.T), surface pavement layers age and accident rates.

II. REVIEW OF LITERATURE

The notion that friction coefficients are a significant contributory factor in traffic crashes has been firmly entrenched in the literature. As a result, many highway authorities have set minimum friction requirements for road surfaces, below which the probability of a crash is considered unacceptably high. The safety benefit ascribed to friction coefficients arises from its ability to facilitate various vehicle maneuvers, most notably breaking and cornering [4].

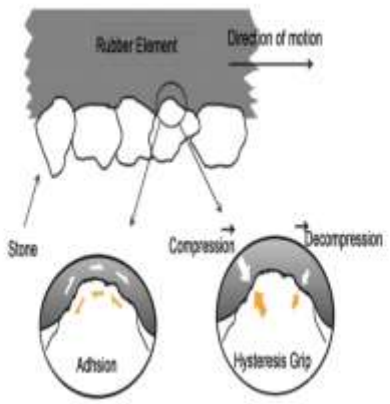
Pavement friction depends on both the micro-texture of aggregates and the macro-texture of the overall pavement surface. Micro-texture, usually defined as small-scale texture up to 0.5 mm wavelength, is largely a function of the surface texture of aggregate particles. Macro-texture is a larger texture between about 0.5 mm and 50 mm wavelength. Micro-texture affects the adhesion area between aggregate and tire rubber and controls the pavement friction level at low speeds, while macro-texture has a greater effect on hysteresis friction. Unlike micro-texture, macro-texture also helps to provide a drainage channel for water to escape. Macro-texture assumes a greater role at high speeds and is the controlling factor in the speed dependency of friction [5].

Pavement Friction Mechanism

Pavement friction could be a resistive force that is generated once a tire roll or slides on the pavement surface. Pavement friction is developed due to the tire-pavement interaction at the contact surface. The friction force developed at the contact surface depends upon the tire properties. The friction force developed by rubber (tire) is comprised of 2 main parts referred to as Adhesion and Hysteresis. Those 2 parts are shown in Figure 1 that explains wherever the resistance force comes from [6].

- Adhesion: is that the friction force developed by shearing between tire and pavement at the contact area. The relationship between adhesion and friction has long been a topic of significant interest in Tribology [7]. This friction force is mainly contributed by the micro-texture (surface roughness) of the road pavement as a result of adhesion force is developed at the tire-pavement interface. The little scale bonding and interlocking between rubber and pavement mixture provide rise to the current adhesion. At typical driving speed adhesion accounts for two-thirds of friction resistance developed at the tire-pavement interface.
- Hysteresis: Tire rubber stores deformation energy once the tire compresses against the pavement. When the tire involves the state of relaxation, a part of the energy hold on is recovered, whereas a part of the energy is lost because of the type of energy. This loss of energy induces the friction force that is named hysteresis. The hysteresis is mainly dependent on the macro-texture (surface roughness) of the pavement since the tire makes an envelope surface at the tire-pavement interface [8].

Other parts of the friction force developed by rubber contribute to the whole friction force like tire rubber shear, however, they are insignificant compared with adhesion and hysteresis. The sum of those 2 parts accounts for the full friction developed within the interface of the tire-pavement interface.



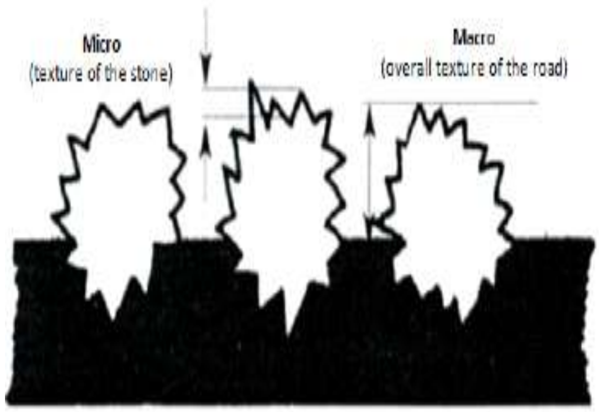


Figure 1: Adhesion and Hysteresis Mechanism [9]

Parameters Affecting Friction Value

Different parameters are known within the literature to possess an effect on the tire-pavement friction interaction. Generally, these factors are typically sorted into four different classes [10]:

1. Pavement surface characteristics.
2. Vehicle operational parameters.
3. Tire characteristics.
4. Environmental factors.

III. METHODOLOGY

In this study, tested roads have been evaluated using a portable skid resistance mechanism using (B.P.) following (ASTM E303-93) procedure which records the point friction value for each point. Field tests were carried out depending on the availability of selected road data in the General Authority for Roads in Egypt. To overcome the possible effect of climatic variation on friction test results, the field tests were performed in the same region during the same summer temperature (30°c to 38°c) at which surface skid resistance is expected at its lowest condition due to asphalt high viscosity as stated by National Cooperative Highway Research Program (NCHRP) in 2009 [11].

- **British Pendulum**

The British Pendulum tester is a dynamic pendulum impact-type tester used to measure the energy loss when a rubber slider edge is propelled over a test surface as shown in Figure 2. The tester is suited for laboratory as well as field tests on flat surfaces, and for polish value measurements on curved laboratory specimens from accelerated polishing-wheel tests [12].

Pendulum tester is used to determine the frictional properties of a test surface. The test surface is cleaned and thoroughly wetted prior to testing. The pendulum slider is positioned to barely come in contact with the test surface prior to conducting the test. The pendulum is raised to a locked position and then released, thus allowing the slider to make contact with the test surface. A drag pointer indicates the British Pendulum (Tester) Number. The greater the friction between the slider and the test surface, the more the swing is retarded, and the larger the BPN reading. Four swings of the pendulum are made for each test surface [13].

Field test surfaces shall be free of loose particles and flushed with clean water. The test surface does not have to be horizontally provided the instrument can be leveled in working position using only the leveling screws and the pendulum head will clear the surface.

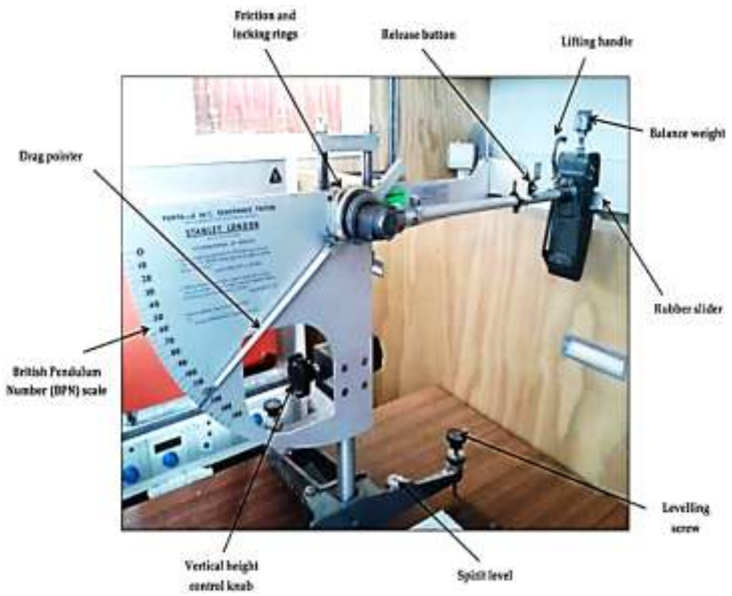


Figure 2: British Pendulum Tester Apparatus [14]

- **Selected Roads for This Study**

Selected roads covered Main Egyptian road types as rural desert and agriculture according to road location also urban and rural according to road function. The selection was depending on the availability of selected road data in General Authority for Roads in Egypt.

The test sections cover very recently constructed project to 17 years old project. General information on each test sections such as; route name, construction, and test date, available accidents data, average daily traffic were collected and presented in Table 1.

- **Study framework**

A framework has been adopted for field tests for selected roads by a sequence of steps outlined below:

1. A preliminary study of roads was conducted to know general information about selected roads such as a number of traffic lanes and the type of transport available to choose the most suitable time to take readings.
2. The selected roads were divided into sectors, according to the division of the General Authority for Roads, where the tested sections match data provided by the Authority.
3. The data necessary (ADT, surface layer construction date or last massive maintenance for surface layers, number of accidents that occur in straight lines according to police records) to reach the objective of the study were collected.
4. Field tests were carried out as illustrated in the map shown in Figure 3 to collect pavement surface friction and texture data from selected pavement sections and record pavement surface friction numbers.
5. Simple and multiple regression analysis have done using Predictive Analysis SoftWare PASW program.

IV. DATA ANALYSIS

Collected data were used to investigate the relationships between friction value and Cumulative Traffic (CT), surface ages and accident rates. Two regression analyses were used; first simple linear regression for friction value was used to check the correlation coefficient between this dependent and independent variables. Second stepwise regression analysis was used to select the most affected variables [15].

- **Analysis Methodology**

Evaluation of pavement surface friction needs to make an analysis between friction values that recorded using (B.P.) and the variables that effect on or affected by that value. To achieve this goal the following analytical assumptions have been assumed:

1-There is no statistically significant relationship between friction values and C.T for each road section samples.

2-There is no statistically significant relationship between friction values and surface layer ages for each road section samples.

3-There is no statistically significant relationship between friction values and accident rates for each road section samples.

4-There is no statistically significant relationship between friction values and C.T and surface layer ages for each road section samples.

To verify the previous assumptions statistical analysis has been done for each group, the first step consisted of conducting a regression analysis for each factor that effects on friction number for each road group and calibrates a model for that analysis. Secondly, make a regression analysis for accident rates that affected by friction number. Finally, conclude a regression analysis model that relates all parameters to the friction value to predict the value of it in the future and know the most related effecting factor.

Table 1: Studied Roads Data According to GARBLT in 2017

Road Type	Road Name	Sector Name	Code	Pavement Surface Ages (years)	ADT (veh/day/right lane)	Accidents Number on straight links	Road Length (km)
Desert	Asyuit Desert Rd	Cairo - bani sweif	221	11	4833	3	75
		bani sweif - Cairo	222	11	5282	3	75
	Faiyum Desert Rd	Faiyum - Cairo	220	9	8266	11	75
		Cairo - Faiyum	219	9	7716	9	75
	Ismailia Desert Rd	Ismailia – Cairo 1	217	8	24028	4	85
		Cairo - Ismailia 2	218	8	28994	6	85
	Ismailia – Suez	Ismailia - Fayed	213	9	5297	7	30
		Fayed - Ismailia	214	9	5297	6	30
		Fayed - Suez	215	13	4511	12	40
		Suez - Fayed	216	13	4511	5	40
	Suez Desert Rd	Cairo – Suez 1	212	1	5338	4	100
		Suez - Cairo 2	211	1	7826	6	100
Agriculture	Cairo – Alex Agriculture Rd	Shobra – Banha	411	12	45638	50	50
		Banha – Tanta	412	12	19498	11	35
		Tanta – Damnhour	413	12	14709	70	60
		Damnhour - Alexandria	414	12	15759	70	40
		Alexandria - Damnhour	415	12	17020	72	40
		Damnhour - Tanta	416	12	15878	72	60
		Tanta – Banha	417	12	19922	13	35

		Banha – Shobra	418	12	40845	49	50
	Cairo - Ismailia	Cairo - Belbies	419	17	7587	11	39
		Belbies – Abo Hammad	420	17	5872	11	24
		Abo Hammad - Ismailia	421	17	6942	11	66
		Ismailia - Abo Hammad	422	17	6603	11	66
		Abo Hammad - Belbies	423	17	6335	11	24
		Belbies - Cairo	424	17	7587	11	39
	Faiyum - Baniswief	Faiyum - Baniswief	425	10	1374	3	26
		Baniswief - Faiyum	426	10	1374	3	26
Urban	26 July corridor	Juhayna – Ring Rd	511	13	39814	24	12
		Ring Rd – Juhayna	512	13	41720	24	12
	Ring Road	Suez Rd - Kattamia	513	5	58279	17	3
		Elwarrak – Suez Rd	514	5	36952	22	11
		Elkattamia – Elmansorya	515	5	42395	19	19
		Elwarrak – Elwahat	516	5	50813	15	19
		Alex Ag.Rd - Elwarrak	517	5	24701	7	19
		Alex Ag.Rd – Suez Rd	518	5	39081	19	2

Figure 3: Selected Egyptian Roads for this Study

- **Selected Roads for Friction Regression Analysis**

For Egyptian roads category, selected roads have been divided into sectors, according to GARBLT division. Then, cumulative traffic has been calculated to the right lane as it is expected that right lane exposed to maximum numbers of trucks per surface layer ages as shown in Equation 1; also, accident rates have been calculated as shown in Equation 2. After that, a single regression method has been performed considering one variable (CT or surface layer ages) as independent variables and friction values as the dependent variable. Secondly, a relation between accident rates and friction values has been achieved, but friction values where the independent variable to estimate the predicted accidents rates.

$$CT = ADT * D.D. * LF * RA * 365 \quad (1)$$

$$AR = No.of\ Acc.*(10)^8/(ADT* D.D. * LF *R.L.*365) \quad (2)$$

Where;
CT: Cumulative Traffic (veh.);
ADT: Average Daily Traffic (veh/day);
RA: Road Age (years);
AR: Accidents Rate (Ac. 10^8/veh.km);
RL: Road Length (Km);
Acc.: Accidents Numbers;
D.D.: Directional Distribution;
LF: Right Lane Factor.

- **Friction Regression Analysis**

For all roads categories, all over correlation analysis between friction values and other variables are shown in Tables 3, 4 and 5 which compare between correlation percentages due to the single regression method. The application of single regression analysis between friction values, and CT uses the ENTER method of regression which mean that all independent variables are entered into the equation in (one step), also called "forced entry" for 70% of recorded data, illustrated that there are:

- Good, statistically significant relationship for desert roads at the level of (P-value) 0.00%, where the correlation coefficient (R) is 74.2% and this variation contributes (adjusted R^2) 54.7%, to the interpretation of variance in the dependent variable as shown in Table 2. On the same hand for agriculture roads better statistically significant relationship at the level of 0.0%, where the correlation coefficient (R) is 80.2% and this variation contributes (adjusted R^2) 63.6%, to the interpretation of variance in the dependent variable as shown in Table 3. Moreover, for urban roads, there is a statistical significant relationship at the level of 0.0%, where the correlation coefficient (R) is 87.1%, and this variation contributes (adjusted R^2) 75.1%, to the interpretation of variance in the dependent variable as shown in Table 4. It can be concluded that, the main reason for good relationship between friction value and CT that; a number of total traffic which moves on the pavement surface increase the friction value decrease according to energy losses due to friction forces between tires and surface layers and that led to less of friction value and also the good statically relationship between them and that is clear from significant value (0.0). Friction – CT relationship coefficients that are shown in Tables 5, 6 and 7 indicated that the relationship between those two variables is inverse relationship and the main reason for that is the deterioration for asphalt mix due to friction forces between tire movement and asphalt layer and that can be obtained as shown in Equations 3, 4 and 5.

Table 2: All over Regression Analysis Outputs for Desert Roads

Variable	**Significant Value %**	**Correlation Coefficient (R) %**	**Percent of Contribution (Adjusted R^2) %**
Cumulative Traffic	0.00	74.2	54.7
Surface Age	0.00	82.5	67.7
Accidents Rates	0.10	32.5	9.7

Table 3: Allover Regression Analysis Outputs for Agriculture Roads

Variable	**Significant Value %**	**Correlation Coefficient (R) %**	**Percent of Contribution (adjusted R^2) %**
Cumulative Traffic	0.00	80.2	63.6
Surface Age	49.5	9.7	0.9
Accidents Rates	0.00	74.7	55.0

Table 4: Allover Regression Analysis Outputs for Urban Roads

Variable	**Significant Value %**	**Correlation Coefficient (R) %**	**Percent of Contribution (adjusted R^2) %**
Cumulative Traffic	0.00	87.1	75.1
Surface Age	0.00	76.3	56.9
Accidents Rates	1.00	43.6	16.5

Table 5: Friction – Cumulative Traffic Relationship Outputs for Desert Roads

Model		**Unstandardized Coefficients**		**Standardized Coefficients**	**t- test**	**Significant**
		B	**Std. Error**	**Beta**		
1	(Constant)	71.994	1.843	0.00	39.06	0.00
	Cumulative Traffic	$-1.1353*10*^{-7}$	0.00	-0.742	-11.08	0.0

Table 6: Friction – Cumulative Traffic Relationship Outputs for Agriculture Roads

Model		**Unstandardized Coefficients**		**Standardized Coefficients**	**t-test**	**Significant**
		B	**Std. Error**	**Beta**		
1	(Constant)	70.778	1.979	0.00	35.76	0.00
	Cumulative Traffic	$-5.203*10^{-8}$	0.00	-0.80	-9.48	0.00

Table 7: Friction – Cumulative Traffic Relationship Outputs for Urban Roads

Model		**Unstandardized Coefficients**		**Standardized Coefficients**	**t-test**	**Significant**
		B	**Std. Error**	**Beta**		
1	(Constant)	58.3363	1.4901	0.00	39.147	0.00
	Cumulative Traffic	$-2.390*10^{-8}$	0.00	-0.8712	-10.039	0.00

F = 71.994 - 1.1353*10-7 * (CT) (3)
F = 70.778 – 5.203*10-8 * (CT) (4)
F = 58.3363–2.390*10-8 * (CT) (5)

Where:
F: Friction values (unit less);
CT: Cumulative Traffic (veh.).

Using Equations 3, 4 and 5; the friction values have been calculated for another 30% from recorded data to check the validity of those equations. As shown in Figures (4 to 9) it illustrates the relationships between (measured friction values from the field records using the British Pendulum and calculated friction values using previous equations. For all road categories, analytical results showed that there is a good correlation percent between C.T. and friction values except desert roads the confirmation of analytical equation showed that the percent of correlation is 0.5064 and that is a fair percentage.

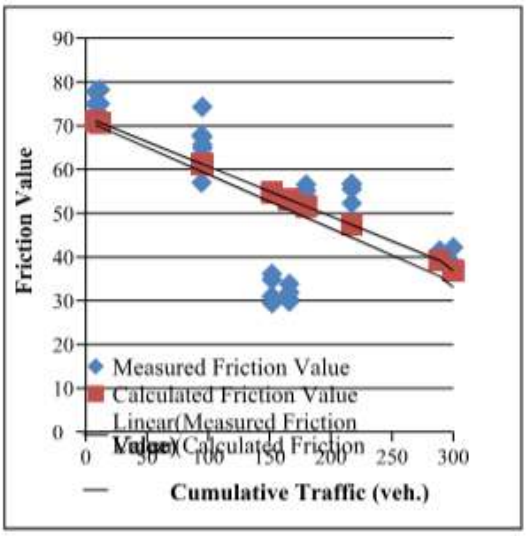


Figure 4: Friction – Cumulative Traffic Relationships for Desert Roads

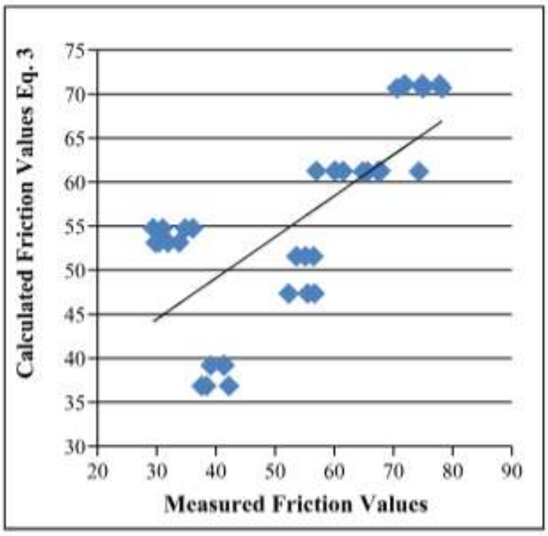


Figure 5: Friction-Cumulative Traffic Relationship Validation for Desert Roads

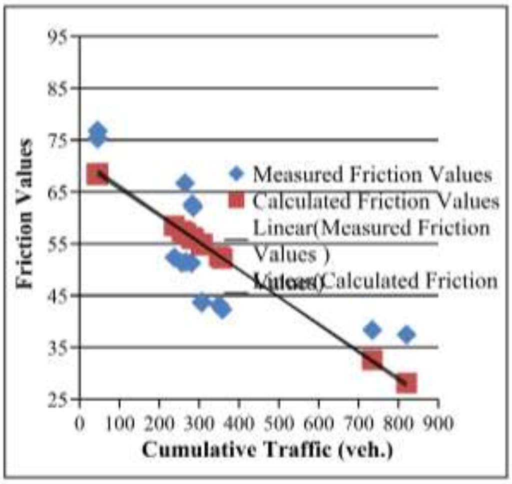


Figure 6: Friction – Cumulative Traffic Relationships for Agriculture Roads

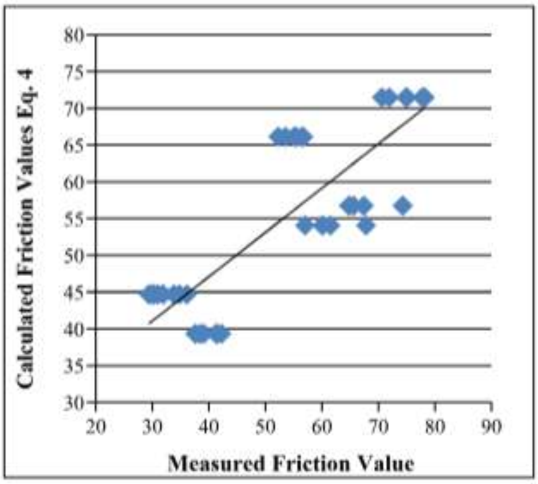


Figure 7: Friction – Cumulative Traffic Relationship Validation for Agriculture Roads

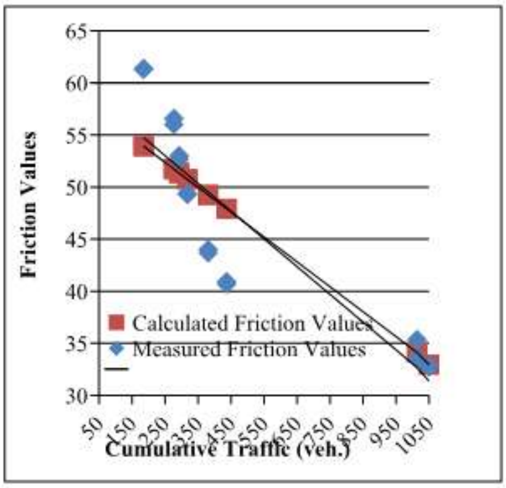


Figure 8: Friction - Cumulative Traffic Relationships for Urban Roads

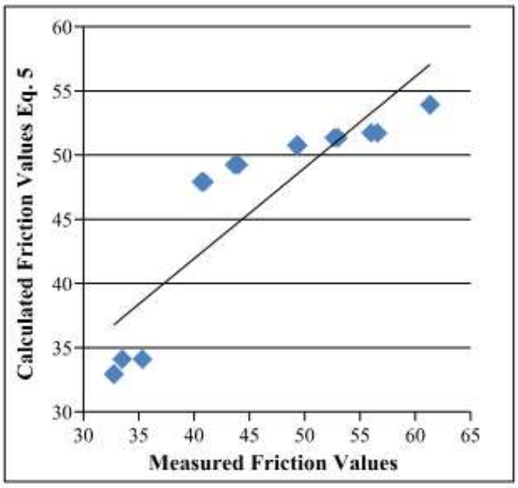


Figure 9: Friction – Cumulative Traffic Relationship Validation for Agriculture Roads

For desert roads, it can be observed that there is medium dispersion for measuring friction value than it is calculated values where correlation equations for each friction values are shown in Figure 4. It can be observed that (R^2) for measuring friction value is 0.5064. On the other hand and based on regression analysis for agriculture roads between friction – CT factor, it can be observed that there is little dispersion for measuring friction value than it is calculated values. It could also be concluded that there is a good agreement for the recent studies which included that friction value is inversely proportional to cumulative traffic for agriculture roads as with a higher number of cumulative traffic; higher erosion percent occurred to surface layer component which has been illustrated in a sign of CT factor in Equation 4. Moreover, Figure 8 illustrated the relationship between measured and calculated friction values for selected roads at the same CT. It can be observed that there is medium dispersion for measuring friction value than it is calculated values. The equation that correlated between them is shown in Figure 9. It can be said that there is good agreement between them where (R^2 = 0.7906).

- By applying single regression method for same 70% of recorded data between friction values and surface layer ages using the ENTER method of regression, it is shown that for desert roads there is a statistically significant relationship at the level of 0.0%, where the correlation coefficient (R) is 82.5%, and this variation contributes (adjusted R^2) 67.7%, to the interpretation of variance in the dependent variable as shown in Table 2. But for agriculture roads there is no statistically significant relationship at the level of 49.5%, where the correlation coefficient (R) is 9.7%, and this variation contributes (adjusted R^2) 0.9%, to the interpretation of variance in the dependent variable as clear in Table 9, and that is because the ADT is extremely different from road to another also the huge gap between the construction date or last massive maintenance among them. Same to desert roads; the analysis for urban roads showed that there is a statistically significant relationship at the level of 0.0%, where the correlation coefficient (R) is 76.3%, and this variable contribute (adjusted R^2) 56.9%, to the interpretation of variance in the dependent variable Friction–surface layer age relationship coefficients for selected roads that shown in Table 5 which indicated that the relationship between those two variables is inverse relationship and the main reason for that are the deterioration for asphalt mix with time through the road age and that can be obtained as shown in Equations 6 and 7.

Table 8: Friction – Surface Age Relationship Outputs for Selected Desert Roads

Model		Unstandardized Coefficients		Standardized Coefficients	t- test	Significant
		B	Std. Error	Beta		
1	(Constant)	72.823	1.493	0.00	48.791	0.0
	Surface age	-1.340	0.092	-0.825	-14.596	0.0

Table 9: Friction-Surface Age Analysis Results for Agriculture Roads

Model	R	R^2	Adjusted R^2	Std. The error of the Estimate	Significant
1	0.097	0.010	0.009	13.15	0.495

Table 10: Friction – Surface Age Relation Outputs for Selected Urban Roads

Model		Unstandardized Coefficients		Standardized Coefficients	t- test	Significant
		B	Std. Error	Beta		
1	(Constant)	56.713	1.9555	0.00	29.00	0.00
	Surface age	-1.289	0.1930	-0.76292	-6.675	0.00

F = 72.823 – 1.340 * (SA) (6)
F = 56.7135 – 1.289 * (SA) (7)
Where;
F: Friction number (unit less);

SA: Surface age (years).

Using Equation 6; the friction values have been calculated for another 30% from recorded data to check the validity of Equation 6. Figure 10 illustrates the relationship between (measured friction values from the field using British Pendulum) and calculated friction values using Equation 6 It can be observed that there is medium dispersion for measured friction value than it is calculated values where correlation equations for each friction values are shown in Figure 11 also it illustrates the relationship between measured and calculated friction as it shows the equation that correlated between calculated and measured friction values for desert roads. It can be said that there is good agreement between them where (R^2 = 0.6768). Although high correlation coefficient and percent of contribution factor between friction values and road age for selected urban roads but the previous relationship Equation 7 is not verifiable due to same last massive maintenance time for all ring road links and that is led to same friction values.

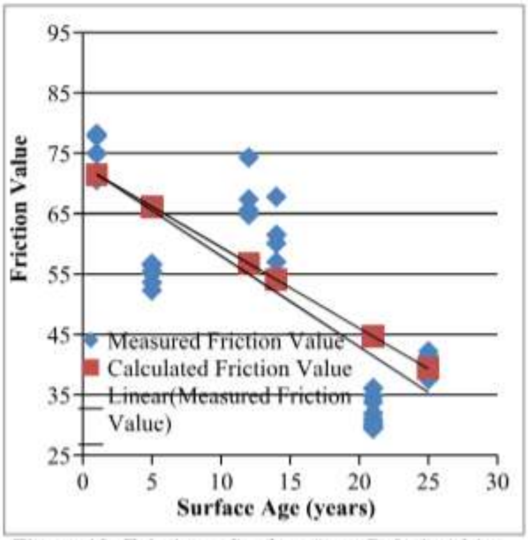


Figure 10: Friction – Surface Ages Relationships for Desert Roads

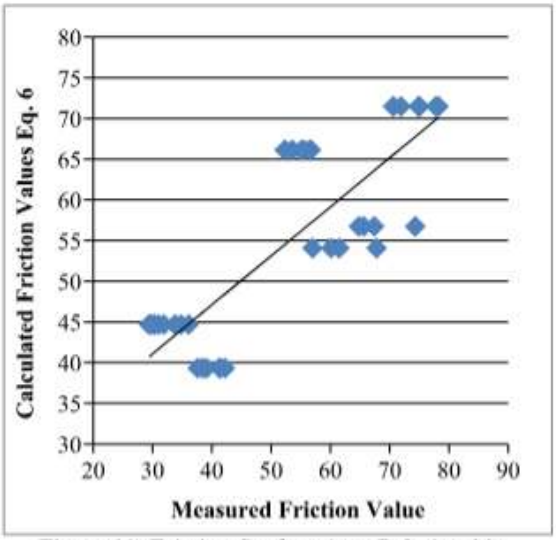


Figure 11: Friction-Surface Ages Relationship Validation for Desert Roads

According to previous figures it can be observed that there is a large dispersion for measuring friction value than it is calculated values. Although the friction – surface ages relation is better than friction – CT relation by nearly 33% as correlation coefficient increases from 0.5064 to 0.6768. This concept agreed with literature studies which evaluate friction values with other parameters in other countries like the USA in 2011, so it can be concluded that friction – road ages relation is more applicable than friction – cumulative traffic relation [16].

- On the other hand; the application of single regression method between friction values and accidents rates using ENTER method of regression for the same 70% from recorded data illustrated that there is a weak statistically significant relationship at the level of 0.1%, where the correlation coefficient (R) is 32.5%, and this variable contribute (adjusted R^2) 9.7%, as shown in Table 11 this week relationship caused due to different factors that contribute to causing accidents; on the other hand that weak relation could be due to the big stopping sight distance for a vehicles that let the drivers to have an adequate time and distance to stop the vehicles under critical conditions so with low value of friction the number of accidents did not increase extremely which is clear in small factor of friction value (0.024) in Table 11. Moreover, for agriculture roads, there is a statistically significant relationship at the level of 0.0%, where the correlation coefficient (R) is 74.7%, and this variation contributes (adjusted R^2) 55.0%, to the interpretation of variance in the dependent variable as shown in Table 3. This analytical relationship has been produced and that supports the literature review about the relations between friction values, and CT and accidents rates which is clearly illustrated in the R^2 value of each relation. But for urban roads, there is a weak statistically significant relationship at the level of 1.0%, where the correlation coefficient (R) is 43.6%, and this variation contributes (adjusted R^2) 16.5%, to the interpretation of variance in the dependent variable as shown in Table 4. Agriculture and urban relationships outputs are shown in Tables 12 and 13 respectively.

Table 11 Friction – Accidents Rates Relationship Outputs for Desert Roads

Model		Unstandardized Coefficients		Standardized Coefficients	t- test	Significant
		B	Std. Error	Beta		
1	(Constant)	-0.261	0.400	0.00	-0.652	0.516
	Friction values	0.024	0.007	0.325	3.434	0.01

Table 12 Accidents Rates – Friction Relation Outputs for Selected Agriculture Roads

Model		Unstandardized Coefficients		Standardized Coefficients	t- test	Significant
		B	Std. Error	Beta		
1	(Constant)	-3.522	0.936	0.00	-3.760	0.00
	Friction value	0.131	0.016	0.747	7.953	0.00

Table 13 Accidents Rates – Friction Relation Outputs For Selected Urban Roads

Model		Unstandardized Coefficients		Standardized Coefficients	t- test	Significant
		B	Std. Error	Beta		
1	(Constant)	-1.070	1.154	0.00	-0.927	0.036
	Friction values	0.067	0.024	0.435	2.738	0.010

$$AR = -3.522 + 0.131 * F \quad (8)$$
$$AR = -1.070 + 0.067 * F \quad (9)$$

Where:
AR: Accidents rates (Ac. 10^8 /veh.km);
F: Friction value (unit less).

Accident rates - friction relationship analysis outputs coefficients for studying roads that shown in Tables 14, 15 and 16 indicated that the relationship between these two variables is a directly proportional relationship and that is different to the concept that with low pavement surface friction value the rates of accidents increase. However, on the other hand accidents rates

4.4. Multiple Regression Analysis for Selected Roads

In multiple linear regression analysis, having several independent correlated variables in the model will affect the values of the regression coefficients and in some cases cause the signs to switch to counterintuitive values. By applying multiple regression between friction values as a dependent variable and the other corresponding CT and surface ages as independent variables using stepwise regression method for 70% of recorded data for selected roads category, all over results illustrated in Tables 14, 15, 16 and 17.

Table 14: Multiple Regression Analysis Results for Roads

Variable	Significant Value %	% (R)Correlation Coefficient	% (Percent of Contribution(adjusted R^2
Desert	0.00	85.3	72.3
Agriculture	0.00	85.6	72.2
Urban	0.00	97.8	95.5

Table 15: Friction – (Cumulative Traffic and Surface Age) Stepwise Outputs for Desert Roads

Model	Unstandardized Coefficients	Standardized Coefficients	t- test	Significant

		B	Std. Error	Beta		
1	(Constant)	72.8226	1.49	0.00	48.791	0.0
	Surface Age	-1.3400	0.0918	-0.825	-14.595	0.0
2	(Constant)	75.1826	1.495	0.00	50.288	0.0
	Surface Age	-0.9775	0.121	-0.602	-8.032	0.0
	Cumulative Traffic	$-4.774*10^{-8}$	1.	-0.312	-4.167	0.0

Table 16: Friction – (Cumulative Traffic and Surface Age) Stepwise Outputs for Agriculture Roads

Model		Unstandardized Coefficients		Standardized Coefficients	t- test	Significant
		B	Std. Error	Beta		
1	(Constant)	70.778	1.979		35.763	0.0
	Cumulative Traffic	$-5.203*10^{-8}$	.000	-0.802	-9.485	0.0
2	(Constant)	86.024	4.123		20.862	0.0
	Cumulative Traffic	$-6.199*10^{-8}$	0.000	-0.955	-11.527	0.0
	Surface age	-0.641	.157	-0.337	-4.072	0.0

Table 17: Friction – (Cumulative Traffic and Road Age) Stepwise Outputs for Urban Roads

Model		Unstandardized Coefficients		Standardized Coefficients	t- test	Significant
		B	Std. Error	Beta		
1	(Constant)	58.336	1.490		39.147	0.00
	Cumulative Traffic	$-2.3906*10^{-8}$	0.00	0.00	-0.871	0.00
2	(Constant)	57.834	0.632		91.508	0.00
	Cumulative Traffic	$-8.318*10^{-8}$	0.00	0.00	-3.031	0.00
	Surface age	3.725	3.725	0.306	2.205	0.00

According to multiple analytical regression results that shown in Tables 14, 15, 16 and 17, the following Equations 10, 11 and 12 are produced. It can be concluded that the best relationship for each road category has been driven between friction values and (cumulative traffic and surface ages) as multiple regression and that is clearly illustrated from correlation coefficient (R).

F = 75.1826 - 4.774*10-8 (CT) - 0.9775 (RA) (10)
F = 86.024 - 6.199*10-8 (CT) -0.641 (RA) (11)
F = 57.834 - 8.318*10-8 (CT) + 3.725(RA) (12)

Where:
F: Friction values (unitless)
RA: Road age (years)
CT: Cumulative Traffic (veh.)

Using Equations 10, 11 and 12, for 30% of recorded data to check the validity of analytical equation, the friction values have been calculated for each road section as shown in Figure 13 as it illustrates the relationships between (measured friction values from the field using B.P. and calculated friction values using previous Equations.

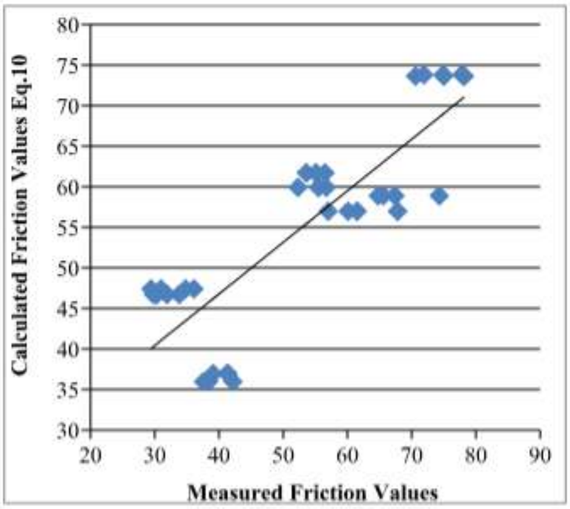


Figure 12: Friction – (Cumulative Traffic and Surface Ages) Relationship Validation for Desert Roads

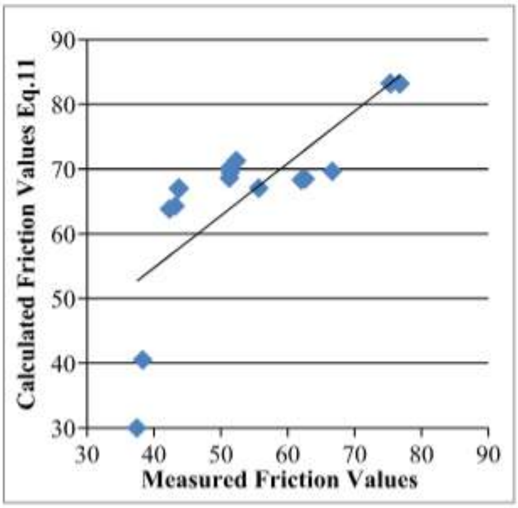


Figure 13: Friction – (Cumulative Traffic and Surface Ages) Relationship Validation for Agriculture Roads

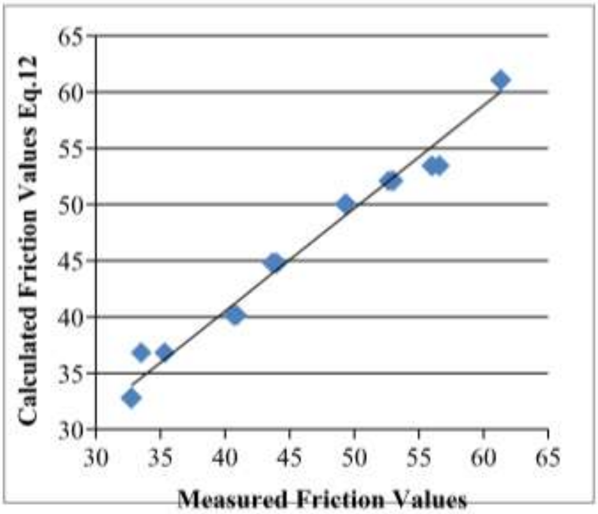


Figure 14: Friction – (Cumulative Traffic and Surface Ages) Relationship Validation for Urban Roads

Based on Figures 12, 13 and 14 it could be illustrated that urban roads multiple regression analysis has the minimum dispersion of measured – calculated friction values and that led to conclude that the best applicable equation is friction – (cumulative traffic and road ages) and that is agreed with previous studies in this field of research as Tim Nelson, Luis G. Fuentes, and Yogendra Prasad Subedi stated in their studies for friction influencing factors [17],[18].

V. SUMMARY AND CONCLUSIONS

The objective of this study was to investigate the relationship between friction values using a British Pendulum (B.P.) and other factors such as cumulative traffic, surface ages, and accident rates. Based on the field investigation of pavement friction values it could be included that the C.T. and surface age is the main effective factor in friction values which explained by the deterioration for asphalt mix due to friction forces between tires movement and asphalt layer. The deterioration happened to pavement layer due to a climatic effect like frequent temperatures change between hot and cool during the night and the day also that difference between summer and winter, as well as rain and surface water on asphalt layer.

Moreover, the following conclusions have been drawn:

- Surface ages factor was the most affected factor that related to recorded friction values for Egyptian desert roads.
- For agriculture roads and urban roads, it is clear that multiple factors (road ages and cumulative traffic) have recorded the most correlation percent (R).
- According to the regression analysis for friction and other parameters, it can be concluded that surface friction values are highly affected by surface ages and cumulative traffic (asphalt mix deterioration) over a time.

REFERENCES

[1]. Mohamed N., "Development Predictive Models for Accident Characteristics and ITS Effects on National Economy in Egypt" M.Sc. Thesis, Al-Azhar University, 2016

[2]. World Health Organization (WHO), "Road Traffic Injuries, Fact Sheet N°358", March 2013.

[3]. Greibe P., "Braking Distance, Friction and Behavior", Trafitec Denmark, July 2007.

[4]. Erik T.; "The Determination of the Relationship between Friction and Traffic Accidents"; University of Hassel, 2012.

[5]. Lu Q. and Steven B., "Friction Testing of Pavement Preservation Treatments: Literature Review", Technical Memorandum: UCPRC-TM-2006-10, 2006.

[6]. Gerardo W., Kevin K., Edgar D., and Shahriar N., The Little Book of Tire-Pavement Friction", Version 1.0, September 2012.

[7]. Qing Z., Yue Q., Louis G., Tahir C., and William A., "Origin of Static Friction and its Relationship to Adhesion at the Atomic Scale", Physical Review, B 75, 144114, April 2007.

[8]. Luis G., "Investigation of the Factors Influencing Skid Resistance and the International Friction Index" Ph.D. Thesis, University of South Florida, November 2009.

[9]. Behrouz M., Hamzeh Z., Mohsen Z, Fereisoon M., "Pavement Friction and Skid Resistance Measurement Methods: A Literature Review", Open Journal of Civil Engineering, ISSN 2164-3172, June 2016.

[10]. Hall A.; 2009, "Guide for Pavement Friction", National Cooperative Highway Research Program.

[11]. Adla Ragab and Hisham Fouad; 2009; "Roads and highways in Egypt reform for engineering efficiency"; The Egyptian center for economic studies.

[12]. American Society for Testing and Materials, "Standard Test Method for Measuring Surface Frictional Properties Using the British Pendulum Tester1" ASTM, 2003.

[13]. ASTM 2009 American Society for Testing and Materials, "Standard Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire", Standard No E274-06, ASTM 2009.

[14]. Mohamed N., "Relationship between Traffic Flow Characteristics and Pavement Conditions on Roads in Egypt" Ph.D. Thesis, Al-Azhar University, 2009.

[15]. Erhan B. and Zeki K., "Reliability of British Pendulum Test on Macrotextured Surfaces", International Journal of Innovation Sciences and Research, Vol.5, No.1, pp.611-616, January- 2016.

[16]. Vivek L., "Evaluation of Louisiana Asphalt Pavement Friction", M.Sc. Thesis, Louisiana State University, December 2011.

[17]. Yogendra P., "Evaluation of Louisiana Friction Rating Table by Field Measurements", M.Sc. Thesis, Tribhuvan University, Nepal, August 2015.

[18]. Tim N., "Evaluation of Skid Resistance of Turf Drag Textured Concrete Pavements", Minnesota Department of Transportation, April 2011.

Ahmed M. Abdallah " Assessment of Surface Friction Characteristics for Egyptian Highways" International Journal Of Engineering Research And Development , vol. 15, no. 1, 2019, pp 41-54