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Determination of the Influence of Pavement Friction on the Initial Velocity Using the Accident Reconstruction Engineering Principles

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Abstract: *Several studies were conducted on the accidents of cars using the fundamental principles of physics and engineering including Newton's Laws of Motion and First Law of Thermodynamics. The objective of this study is to determine the influence of and pavement friction on the initial velocity. Regression analysis on the results of these variables was conducted. Excellent correlation coefficient was found for the relationship at α = 0.05 significance level.*
Keywords: *Accident Reconstruction, First Law of Thermodynamics, Initial Velocity, Pavement Friction, Regression Analysis.*

I. INTRODUCTION

Accident reconstructing engineering is the planning, surveying, measuring, investigating, analyzing, and report making process on the intricate engineering details of how accidents occurred. The analysis and conclusions are based on the extensive application of fundamental principles of physics and engineering including Newton's Laws of Motion [1] and First Law of Thermodynamics [2]. The first law of thermodynamics when applied to accidents states that the total energy before and after the accident will be the same. The input variables include roadway, vehicle, driver and environmental conditions. Accident reconstruction engineering studies can be utilized by the industry, city and state governments for modifying the structural facilities such as roads. The modifications may include obtaining improved friction factors, increased number of lanes and lane widths and better site distances. Vehicle manufacturers use the results of the studies for developing better designs of vehicles. Some of the recent vehicles may use event data recorder containing information on the speed of the vehicle before and at the time of the accident. Some manufacturers, such as GM and Ford, allow downloading the information from these boxes after an accident [3]. The results of the accident reconstruction studies are also used for producing better navigations aids to assist the drivers.

In this study the guidelines of Accreditation Commission for Traffic Accident Reconstruction (ACTAR) [4] are used. There are many research studies on the application of accident reconstruction engineering principles. One of the most important one is that of Hurt's [5]. Hurt found that motorcyclists needed to develop their capabilities on controlling skids and proper use of helmets significantly reduced head injuries. Hurt further found that out of all the turning movements, the left turners were involved in the accidents while turning in front of the oncoming motorcycles.

II. SCOPE OF THE STUDY

The study is limited to the accidents caused by negligent drivers of cars hitting the parked cars. All the accidents caused elastic deformations only. There are no significant plastic deformations.

III. METHODOLOGY

C2 was a parked car by the side of the road. The speed limit of the road is 15 mph. C1 was driven by a negligent driver. The friction coefficients of the shoulder and pavement were measured. C1 saw C2 too late and hit the brakes. C1 skidded and hit C2. C2 skidded on to the shoulder and stopped. In most of the cases C2 was damaged and its driver was injured. As the plaintiff, C1's driver sued the negligent driver of C1. In most of the cases C2 driver underestimated his or her speed at the time of the accident.

Parked vehicle Car 2

The following steps were followed.

1. Deceleration = Friction factor * acceleration due to gravity
2. Final velocity of C2 = 0
3. Initial velocity of C2 is shown in the following equation 1.

$$u = \sqrt{2 * a * s} \tag{1}$$

Where, u= initial velocity of the vehicle, ft/sec
a= deceleration of the vehicle, ft/sec^2
s= skidded distance, feet

4. The total product of mass and velocity of Car1 is equal to that of Car 2 as shown in the following equation 2.

$$M_2 u_2 = m_1 u_1 \quad (2)$$

Where, m_2= mass of vehicle C2 and u_2 is the velocity of C2. M_1= mass of C1 and u_1 = velocity of C1.

Car 1

Deceleration was calculated by using equation1.
Final velocity was calculated by the following equation 3.

$$u = \sqrt{v^2 - 2 * a * s} \quad (3)$$

Where, u= initial velocity of the vehicle, ft/sec
v=final velocity, ft/sec
a= deceleration of the vehicle, ft/sec^2
s= skidded distance, feet

IV. RESULTS AND DISCUSSION

The following assumptions were made in this study

1. The energy lost in sound produced by the accident is negligible
2. The energy lost in causing the slight angular movement of the vehicle is negligible.

Professional engineering principles allow the application of the above two assumptions in the appropriate engineering calculations.

Table 1 shows the Engineering Calculations for Mixed Variables for Case 1 through Case 5 for Determininig the Initial Velocity while Table 2 gives the Engineering Calculations for Mixed Variables for Case 6 thorugh 10 for Determininig the Initial Velocity.

Engineering Calculations for Case 1 through Case 5; Case 6 through Case 10; Case 11 through Case 15; and Case 16 through Case 20 for Determininig the influence of Pavement Friction on the Initial Velocity are given in Tables 3, 4, 5, and 6 respectively.

The following regression relationship was found with statistically significant correlation coefficient for predicting the performance of the engineering variables. The relationship was significant at $\alpha = 0.05$ significance level [6,7,8].

Initial velocity is directly to proportional pavement fraction with a linear correlation with R = 0.997 as given in Fig. 1.

Table 1. Engineering Calculations for Mixed Variables for Case 1 through Case 5 for Determininig the Initial Velocity.

	Case 1	**Case 2**	**Case 3**	**Case 4**	**Case 5**
Car2					
Final velocity, ft/sec	0	0	0	0	0
Skidded distance, ft	25	49	30	54	62
Acceleration, ft/sec^2	12.24	12.24	12.24	12.24	12.24
Initial velocity, ft/sec	24.73	34.63	27.1	36.35	38.95
Weight, pounds	2100	4000	5200	3800	6000
Car1					
Weight, pounds	3900	5320	6100	2750	5350
Weight Ratio, C2/C1	0.53	0.75	0.85	1.38	1.12
Final Velocity, ft/sec	13.32	26.04	23.10	50.24	43.69

Skidded distance, ft	4	16	23	46	31
Acceleration, ft/sec^2	-9.66	-9.66	-9.66	-9.66	-9.66
Initial velocity, ft/sec	10.00	19.20	9.45	40.44	36.19

Table 2. Engineering Calculations for Mixed Variables for Case 6 through Case 10 for Determinining the Initial Velocity.

	Case 6	**Case 7**	**Case 8**	**Case 9**	**Case 10**
Car2					
Final velocity, ft/sec	0	0	0	0	0
Skidded distance, ft	38	52	54	35	60
Acceleration, ft/sec^2	12.24	12.24	12.24	12.24	12.24
Initial velocity, ft/sec	30.50	35.67	36.35	29.27	38.32
Weight, pounds	5650	4700	4800	6420	3480
Car1					
Weight, pounds	4760	3450	2480	5200	5460
Weight Ratio, C2/C1	1.18	1.36	1.93	1.23	0.63
Final Velocity, ft/sec	36.20	48.60	70.37	36.13	24.42
Skidded distance, ft	52	43	8	39	19
Acceleration, ft/sec^2	-9.66	-9.66	-9.66	-9.66	-9.66
Initial velocity, ft/sec	17.49	39.13	69.26	23.50	15.15

Table 3. Engineering Calculations for Case 1 through Case 5 for Determinining the Relationship between Pavement Fraction and Initial Velocity.

	1	**2**	**3**	**4**	**5**
Car2					
Final velocity, ft/sec	0	0	0	0	0
Skidded distance, ft	20	20	20	20	20
Acceleration, ft/sec^2	12.88	12.88	12.88	12.88	12.88
Initial velocity, ft/sec	22.69	22.69	22.69	22.69	22.69
Weight, pounds	2000	2000	2000	2000	2000
Car1					
Weight, pounds	2000	2000	2000	2000	2000
Weight Ratio, C2/C1	1	1	1	1	1
Pavement Fraction	0.1	0.15	0.2	0.25	0.3
Final velocity,	22.69	22.69	22.69	22.69	22.69

ft/sec					
Skidded distance, ft	10	10	10	10	10
Acceleration, ft/sec^2	0.1*32.2= 3.22	0.15*32.2= 4.83	0.2*32.2= 6.44	0.25*32.2= 8.05	0.3*32.2= 9.66
Initial velocity, ft/sec	21.23	20.45	19.65	18.82	17.94

Table 4. Engineering Calculations for Case 6 through Case 10 for Determininig the Relationship between Pavement Fraction and Initial Velocity.

	6	**7**	**8**	**9**	**10**
Car2					
Final velocity, ft/sec	0	0	0	0	0
Skidded distance, ft	20	20	20	20	20
Acceleration, ft/sec^2	12.88	12.88	12.88	12.88	12.88
Initial velocity, ft/sec	22.69	22.69	22.69	22.69	22.69
Weight, pounds	2000	2000	2000	2000	2000
Car1					
Weight, pounds	2000	2000	2000	2000	2000
Weight Ratio, C2/C1	1	1	1	1	1
Pavement Fraction	0.35	0.4	0.45	0.5	0.55
Final velocity, ft/sec	22.69	22.69	22.69	22.69	22.69
Skidded distance, ft	10	10	10	10	10
Acceleration, ft/sec^2	0.35*32.2= 11.27	0.4*32.2= 12.88	0.45*32.2= 14.49	0.50*32.2= 16.1	0.55*32.2= 17.71
Initial velocity, ft/sec	17.02	16.04	15.01	13.89	12.68

Table 5. Engineering Calculations for Case 11 through Case 15 for Determininig the Relationship between Pavement Fraction and Initial Velocity.

	11	**12**	**13**	**14**	**15**
Car2					
Final velocity, ft/sec	0	0	0	0	0

Skidded distance, ft	20	20	20	20	20
Acceleration, ft/sec^2	12.88	12.88	12.88	12.88	12.88
Initial velocity, ft/sec	22.69	22.69	22.69	22.69	22.69
Weight, pounds	2000	2000	2000	2000	2000
Car1					
Weight, pounds	4000	4000	4000	4000	4000
Weight Ratio, C2/C1	2	2	2	2	2
Pavement Fraction	0.1	0.15	0.2	0.25	0.3
Final velocity, ft/sec	45.39	45.39	45.39	45.39	45.39
Skidded distance, ft	10	10	10	10	10
Acceleration, ft/sec^2	0.1*32.2= 3.22	0.15*32.2= 4.83	0.2*32.2= 6.44	0.25*32.2= 8.05	0.3*32.2= 9.66
Initial velocity, ft/sec	44.68	43.95	43.58	43.21	42.84

Table 6. Engineering Calculations for Case 16 through Case 20 for Determininig the Relationship between Pavement Fraction and Initial Velocity.

	16	**17**	**18**	**19**	**20**
Car2					
Final velocity, ft/sec	0	0	0	0	0
Skidded distance, ft	20	20	20	20	20
Acceleration, ft/sec^2	12.88	12.88	12.88	12.88	12.88
Initial velocity, ft/sec	22.69	22.69	22.69	22.69	22.69
Weight, pounds	2000	2000	2000	2000	2000
Car1					
Weight, pounds	4000	4000	4000	4000	4000
Weight Ratio, C2/C1	2	2	2	2	2
Pavement Fraction	0.35	0.4	0.45	0.5	0.55
Final velocity,	45.39	45.39	45.39	45.39	45.39

ft/sec					
Skidded distance, ft	10	10	10	10	10
Acceleration, ft/sec^2	0.35*32.2= 11.27	0.4*32.2= 12.88	0.45*32.2= 14.49	0.50*32.2= 16.1	0.55*32.2= 17.71
Initial velocity, ft/sec	42.84	42.46	42.08	41.69	41.31

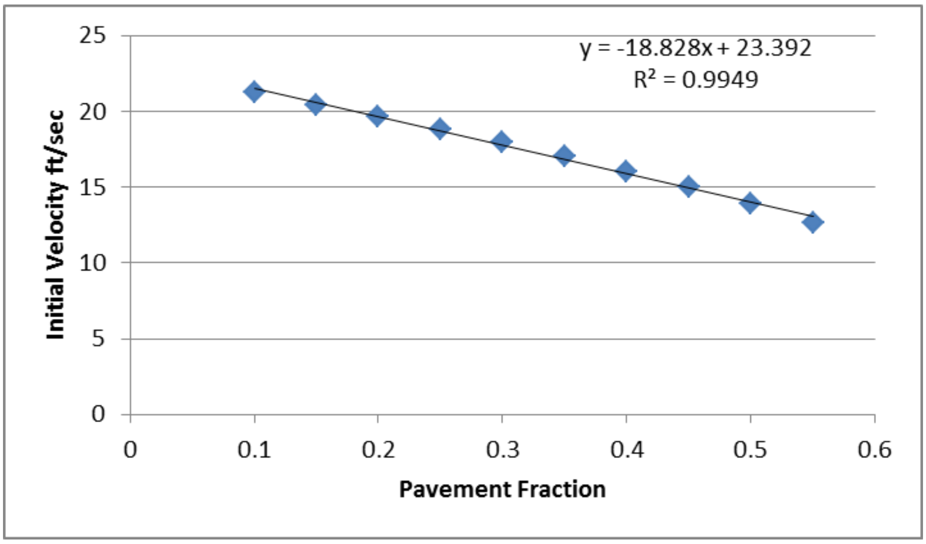

Figure 1. Influence of Pavement Fraction on Initial Velocity

V. CONCLUSION

The following regression relationship was found with statistically significant correlation coefficient for predicting the performance of the engineering variables.

Initial velocity is directly to proportional pavement fraction with a linear correlation with R = 0.997.

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