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Pavement Friction V. Initial Velocity of Vehicle in Chain Accidents on Highways

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ABSTRACT: *The objective of this study is to determine the influence of pavement friction on the initial velocity of the first vehicle in a chain accident on highways involving three vehicles. Regression analysis on the results of these variables was conducted. Excellent correlation coefficient was found for the relationship at α = 0.05 significance level. The influence of Pavement Friction on the Initial Velocity is shown by a quadratic equation (Initial velocity = -0.075 Pavement Friction 2 -1.3359 Pavement Friction + 116.23) with R = 0.99.*
Keywords: *Accident Reconstruction, Chain Accident, 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 the most involved ones 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 [6,7,8,]. All the accidents caused elastic deformations only. There are no significant plastic deformations [9].

III. METHODOLOGY

C1 was travelling at certain speed, feet per second and skidded s feet before hitting C2. One half of the energy was transmitted from C1 to C2. C2 was travelling at certain speed, feet per second before the accident. C2 picked up the energy from C1 and hit C3. The weight ratios of C1/C2 and C2/C3 are noted. Again one half of the energy of C2 was transmitted to C3.

The following equations were used.

1. The total product of mass and velocity of Car2 is equal to that of Car 3 as shown in the following equation.
   $M_2u_2 = m_3\ u_3$ (1)
   Where, m_2= mass of vehicle C2 and u_2 is the velocity of C2. M_3= mass of C3 and u_3 = velocity of C3.
2. Deceleration was calculated by using Equation1.

Final velocity was calculated by the following equation.

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

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 I shows the Engineering Calculations for Mixed Variables for Case 1 through Case 5 for Determininig the Initial Velocity while Table II gives the Engineering Calculations for Mixed Variables for Case 6 thorugh 8 for Determininig the Initial Velocity.
Engineering Calculations for Case 1 through Case 5; Case 6 through Case 10; and Case 11 through Case 15 for Determininig the influence of Pavement Friction on the Initial Velocity are given in Tables III, IV, and V 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 [10,11,12,13].
Fig. 1 shows the influence of Pavement Friction on the Initial Velocity. This relationship is described by a quadratic equation (Initial velocity = -0.075 Pavement Friction ^{2} -1.3359 Pavement Friction + 116.23) with R = 0.99.

Table I. 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**
Car3					
Velocity after the second accident, ft/sec	**86.59**	**83.92**	**118.30**	**124.67**	**134.18**
Weight Ratio, C3/C2	**1.20**	**1.04**	**1.08**	**1.11**	**0.86**
Velocity before the second accident, ft/sec	**50**	**45**	**75**	**80**	**66**
Weight, pounds	**2400**	**2600**	**2800**	**3900**	**2400**
Car2					
Weight, Pounds	**2400**	**2500**	**2600**	**3500**	**2800**
Weight Ratio, C2/C1	**0.50**	**0.74**	**0.68**	**0.83**	**0.68**
Velocity after the first accident, ft/sec	**87.83**	**80.95**	**93.27**	**99.54**	**116.89**
Velocity before the first accident, ft/sec	**40**	**42**	**48**	**53**	**54**
Car1					
Weight, pounds	**4000**	**3400**	**3800**	**4200**	**4100**
Final Velocity (after skidding, and before first accident) ft/sec	**47.83**	**57.28**	**61.95**	**77.57**	**85.89**
Skidded Distance, ft	**10**	**15**	**50**	**18**	**34**
Pavement Friction	**0.33**	**0.33**	**0.33**	**0.33**	**0.33**
Deceleration, ft/sec^2	**10.63**	**10.63**	**10.63**	**10.63**	**10.63**
Initial Velocity, ft/sec	**50**	**60**	**70**	**80**	**90**

Table II. Engineering Calculations for Mixed Variables for Case 6 through Case 8 for Determininig the Initial Velocity.

	Case 6	Case 7	Case 8
Car3			
Velocity after the second accident, ft/sec	**109**	**111.95**	**125.43**
Weight Ratio, C3/C2	**0.92**	**0.95**	**0.95**
Velocity before the second accident, ft/sec	**52**	**58**	**70**
Weight, pounds	**3500**	**4000**	**4200**
Car2			
Weight, Pounds	**3800**	**4200**	**4400**
Weight Ratio, C2/C1	**1.06**	**1.35**	**1.57**
Velocity after the first accident, ft/sec	**104.99**	**102.77**	**105.81**
Velocity before the first accident, ft/sec	**60**	**65**	**72**
Car1			
Weight, pounds	**3600**	**3100**	**2800**
Final Velocity (after skidding, and before first accident) ft/sec	**94.99**	**102.33**	**106.27**
Skidded Distance, ft	**46**	**26**	**38**
Pavement Friction	**0.33**	**0.33**	**0.33**
Deceleration, ft/sec^2	**10.63**	**10.63**	**10.63**
Initial Velocity, ft/sec	**100**	**105**	**110**

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

	Case 1	Case 2	Case 3	Case 4	Case 5
Car3					
Velocity after the second accident, ft/sec	**116.08**	**116.05**	**116.00**	**115.94**	**115.91**
Weight Ratio, C3/C2	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
Velocity before the second accident, ft/sec	**60**	**60**	**60**	**60**	**60**
Weight, pounds	**2800**	**2800**	**2800**	**2800**	**2800**
Car2					
Weight, Pounds	**2800**	**2800**	**2800**	**2800**	**2800**
Weight Ratio, C2/C1	**0.80**	**0.80**	**0.80**	**0.80**	**0.80**
Velocity after the first accident, ft/sec	**112.16**	**112.10**	**111.99**	**111.88**	**111.82**
Velocity before the first accident, ft/sec	**50**	**50**	**50**	**50**	**50**
Car1					
Weight, pounds	**3500**	**3500**	**3500**	**3500**	**3500**
Final Velocity (after skidding, and before first accident) ft/sec	**99.46**	**99.37**	**99.19**	**99**	**98.91**
Skidded Distance, ft	**14**	**14**	**14**	**14**	**14**
Pavement Friction	**0.12**	**0.14**	**0.18**	**0.22**	**0.24**
Deceleration, ft/sec^2	**3.86**	**4.51**	**5.80**	**7.08**	**7.73**
Initial Velocity, ft/sec	**100**	**100**	**100**	**100**	**100**

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

	Case 6	Case 7	Case 8	Case 9	Case 10
Car3					
Velocity after the second accident, ft/sec	**115.88**	**115.85**	**115.82**	**115.80**	**115.77**
Weight Ratio, C3/C2	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
Velocity before the second accident, ft/sec	**60**	**60**	**60**	**60**	**60**
Weight, pounds	**2800**	**2800**	**2800**	**2800**	**2800**
Car2					
Weight, Pounds	**2800**	**2800**	**2800**	**2800**	**2800**
Weight Ratio, C2/C1	**0.80**	**0.80**	**0.80**	**0.80**	**0.80**
Velocity after the first accident, ft/sec	**111.76**	**111.71**	**111.65**	**111.59**	**111.53**
Velocity before the first accident, ft/sec	**50**	**50**	**50**	**50**	**50**
Car1					
Weight, pounds	**3500**	**3500**	**3500**	**3500**	**3500**
Final Velocity (after skidding, and before first accident) ft/sec	**98.82**	**98.73**	**98.64**	**98.55**	**98.46**
Skidded Distance, ft	**14**	**14**	**14**	**14**	**14**
Pavement Friction	**0.26**	**0.28**	**0.30**	**0.32**	**0.34**
Deceleration, ft/sec^2	**8.37**	**9.02**	**9.66**	**10.30**	**10.95**
Initial Velocity, ft/sec	**100**	**100**	**100**	**100**	**100**

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

	Case 11	Case 12	Case 13	Case 14	Case 15
Car3					
Velocity after the second accident, ft/sec	**115.74**	**115.71**	**115.68**	**115.65**	**115.57**
Weight Ratio, C3/C2	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
Velocity before the second accident, ft/sec	**60**	**60**	**60**	**60**	**60**
Weight, pounds	**2800**	**2800**	**2800**	**2800**	**2800**
Car2					
Weight, Pounds	**2800**	**2800**	**2800**	**2800**	**2800**
Weight Ratio, C2/C1	**0.80**	**0.80**	**0.80**	**0.80**	**0.80**
Velocity after the first accident, ft/sec	**111.48**	**111.42**	**111.36**	**111.31**	**111.13**
Velocity before the first accident, ft/sec	**50**	**50**	**50**	**50**	**50**
Car1					
Weight, pounds	**3500**	**3500**	**3500**	**3500**	**3500**
Final Velocity (after skidding, and before first accident) ft/sec	**98.36**	**98.27**	**98.18**	**98.09**	**97.81**
Skidded Distance, ft	**14**	**14**	**14**	**14**	**14**
Pavement Friction	**0.36**	**0.38**	**0.40**	**0.42**	**0.48**
Deceleration, ft/sec^2	**11.59**	**12.24**	**12.88**	**13.52**	**15.46**
Initial Velocity, ft/sec	**100**	**100**	**100**	**100**	**100**

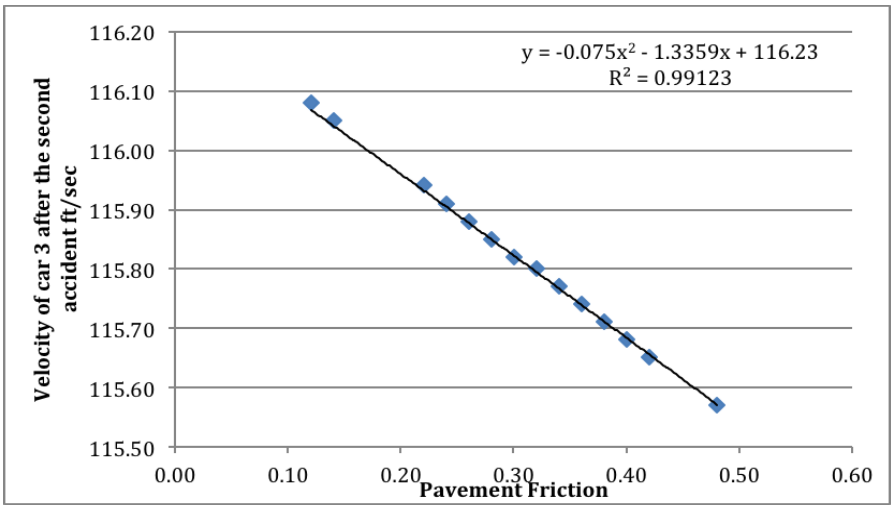

Figure 1 Influence of Pavement Friction on the Initial Velocity

V. CONCLUSIONS

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

The influence of Pavement Friction on the Initial Velocity is shown by a quadratic equation (Initial velocity = -0.075 Pavement Friction ^{2} -1.3359 Pavement Friction + 116.23) with R = 0.99.

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