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## Evaluation of Traffic and Environment Effects on Skid Resistance in California

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**1 ABSTRACT**

2 Skid resistance is one of the important serviceability indicators related to safety on wet  
3 pavements. There is a need to manage skid resistance systematically to maintain the level of  
4 safety performance of roadway surfaces. This study focused on the development of a skid  
5 resistance deterioration model based on the analysis of skid data inventory collected in  
6 California. The California Department of Transportation (Caltrans) has collected skid resistance  
7 data across the complete state highway network over the past two decades using a standard  
8 locked-wheel skid trailer, ASTM E-274. This study utilizes skid data collected on more than 300  
9 miles of asphalt concrete freeway in California over a period of twenty years. Most of the  
10 possible factors found in previous studies to influence skid resistance were considered. Panel  
11 data parameter estimation methods were used. The results indicate that factors with the largest  
12 effects on skid resistance are the age of pavement, ADT, temperature, precipitation, and the  
13 length of the period since the last significant precipitation.  
14

## 1 INTRODUCTION

2 Wet pavement-related collisions represent a significant concern in traffic safety. According to a  
3 U.S. study of collision data in 2001, more than 22 percent of collisions nationwide were weather-  
4 related. Over 16 percent of fatalities and more than 20 percent of injuries in passenger vehicles  
5 occurred in adverse weather and/or on slick pavements. Research has indicated that a major  
6 factor in wet-pavement accidents may be the lack of adequate friction between the tire and the  
7 pavement (1); when the pavement is wet, emergency or panic braking or turning maneuvers may  
8 cause the vehicle tires to slide due to the lower friction between the tires and the pavement.

9 Skid resistance is a measure of the friction developed when a tire is prevented from  
10 rotating and skids along the pavement surface. Therefore, it is one of the important serviceability  
11 indicators of pavement systems in terms of roadway safety, especially on wet pavement. Most  
12 skid resistance measuring techniques involve measuring the force required to drag a non-rotating  
13 tire over wet pavement. One common measure, in the US, is the skid number (SN) which is  
14 specified based on a standard test procedure and apparatus as in ASTM (American Society for  
15 Testing and Materials) E 274 (2). In this procedure, a locked wheel is towed at 40 mph and from  
16 the measured resistance force, the skid number at 40 mph, SN40, is calculated.

17 The skid number on roadways needs to be managed by state highway agencies to  
18 maintain safe levels of skid resistance. In most Departments of Transportation (DOTs) in the  
19 United States, pavements for which the SN40 is below 30 are deemed unacceptable and  
20 corrective actions are taken. If the SN40 is between 30 and 35, the pavement section is  
21 monitored, and more frequent tests are conducted (3). In California, however, there are no  
22 specific guidelines to control skid resistance, and it is not regularly measured.

23 The objective of this study is to evaluate the impacts of traffic and environment effects on  
24 skid resistance. An accurate skid resistance deterioration model would be helpful to support a  
25 strategy for skid resistance inspection of California roadways. For this purpose, a model to  
26 predict SN40 as a function of traffic, temperature, precipitation, and roadway attributes was  
27 developed.

28 This paper is organized as follows. The factors affecting skid resistance, identified in the  
29 literature, are presented in the next section. The third section describes the data used in this  
30 study. The fourth section presents the development of our empirical model, and the fifth section  
31 describes the parameter estimation results and the interpretation. The last section presents  
32 conclusions and future research.

33

## 34 FACTORS AFFECTING SKID RESISTANCE AND THEIR MECHANISMS

35 Five types of factors affecting skid resistance are presented and discussed in this section.

36

### 37 Factors Related to the Pavement

38 Skid resistance depends on a pavement surface's microtexture and macrotexture (4).

39 Microtexture refers to the small-scale texture of the pavement aggregate component which  
40 controls contact between the tire rubber and the pavement surface.

41 The coarser the aggregate, the higher the friction between the tire and the pavement. The  
42 magnitude of this component is determined by two factors: (1) the initial roughness of the  
43 aggregate surface and (2) the ability of the aggregate to retain this roughness against the  
44 polishing action of traffic (3). Accordingly, microtexture is an aggregate-related property.

45 The macrotexture, on the other hand, refers to the large-scale roughness that is present on  
46 the pavement surface due to the arrangement of aggregate particles which controls the escape of

1 water under the tire and hence the loss of skid resistance at high speeds. The magnitude of this  
2 component depends on several factors; the shape, size, gap width, layout, and gradation of the  
3 coarse aggregates used in pavement construction, as well as the particular construction technique  
4 used in the placement of the pavement surface layer (5).

5 To consider the effect of microtexture, aggregate type (6) or Polished Stone Value (PSV)  
6 (7) has been used in the analysis of skid resistance characteristic and was found to be a  
7 significant factor. To describe the effects of macrotexture, the skid resistance of specific  
8 pavement types (8) were studied.

### 9 **Factors Related to Traffic**

10 Polishing of the aggregate is the reduction in microtexture, resulting in the smoothing and  
11 rounding of exposed aggregates. This mechanical wear is due to friction between the tire and the  
12 road surface (9). The higher the traffic volume, the more extensive the polishing action and the  
13 reduction in skid resistance, especially for heavy vehicles. Negative effects of Annual Average  
14 Daily Traffic (AADT), truck volume (7), and lane AADT (6) were found in previous research.

### 16 **Factors Related to Weather**

17 A significant seasonal variation is observed in skid resistance. The general hypothesis presented  
18 by previous researchers (10) to explain this phenomenon is as follows. Prolonged periods of dry  
19 weather allow the accumulation of fine particles that are polished off the pavement surface,  
20 resulting in loss of microtexture and macrotexture. This action, together with contamination from  
21 vehicles such as oil and grease, leads to lower skid resistance.

22 Heavy precipitation works on the pavement surface in the opposite way: fine grit is  
23 flushed out by precipitation, leaving a coarser aggregate surface. Precipitation also cleans the  
24 drainage channels between aggregates and increases the macrotexture of the pavement. Coarser  
25 aggregate surface and increased macrotexture in turn lead to increase in the skid resistance of the  
26 pavement.

27 Skid resistance is also negatively affected by temperature (8, 11). The mechanism  
28 involved in skid resistance loss due to temperature changes is attributed to hysteresis of the  
29 rubber tire. Hysteresis is the energy lost in form of heat upon elastic recovery of the rubber tire,  
30 which is compressed as it slides over the pavement. It follows that at higher temperatures, rubber  
31 becomes more flexible, leading to smaller energy loss. Higher temperatures thus lead to a  
32 decrease in the measured skid resistance.

### 34 **Factors Related to Time**

35 Skid resistance changes over time. Typically, it decreases in the first two years following  
36 construction as the roadway is worn away by traffic, but the decrease slows over the remaining  
37 pavement life because of the weathering effect.

### 39 **Factors Related to Measurement**

40 Measurement error also affects on the measured skid resistance, SN40. The maximum standard  
41 deviation of measurement by ASTM E 274 is reported as 2 units of skid number (2) and many  
42 empirical studies support this assertion (12-14). In addition, the type of non-rotating tire used  
43 (ribbed tire or smooth tire) makes a significant difference in the measurement (14).

1 **DATA**

2 Caltrans provided the data for this study. This data set contains more than 50,000 observations  
 3 along five freeways in California between 1988 and 2008. Each observation consists of SN40,  
 4 location information (route, direction, postmile and lane where measurement was conducted),  
 5 time information (year and month of measurement), geometry information (post speed, ADT,  
 6 surface type, total number of lane, and grade), and measurement information (wheel, weather,  
 7 temperature and test speed).

8 To obtain pavement age information, resurfacing project data from five counties in  
 9 California were used. This data set includes the resurfacing location, type of pavement and the  
 10 duration of construction which provides the age and surface type information of pavement  
 11 sections.

12 Truck volume information at each observation point was estimated by interpolation using  
 13 the annual truck volume data from Caltrans. Weather information such as precipitation and  
 14 temperature at each observation point was obtained from daily weather information at the closest  
 15 weather station among available data provided by the National Oceanic and Atmospheric  
 16 Administration (NOAA) Climatic Data Center.

17 We obtained a total of 2,841 observations of skid resistance measurements on asphalt  
 18 concrete pavements for which all relevant variables were available for further analysis. The  
 19 studied routes are shown in Table 1. The time period was from 1992 to 2007.  
 20  
 21

**TABLE 1 Study Routes**

Routes	District	County	Miles
I-5	6	Kern	44
I-80	3	Yolo and Nevada	46
I-101	1	Humboldt	133
I-101	5	Mono	90
Total			313

22  
 23 **TABLE 2 Factors Affecting Skid Resistance and Their Availability in the Data Set**

Factors	Available Variables in Data Set	Unobservable Variables
Pavement factors	- pavement type	- polished-stone value (PSV) - aggregate type
Traffic factors	- #of commercial vehicles/day - AADT - cumulated traffic	- lane AADT
Environmental factors	- seasonal effects - temperature - amount of precipitation preceding measurement - dry periods preceding measurement	
Time factors	- age of pavement (time after treatment)	
Measurement factors	- test speed	- tester device error - type of tire used

24  
 25

## 1 DEVELOPMENT OF SKID RESISTANCE DETERIORATION MODEL

2 Modeling skid resistance using field data can produce biased or inconsistent parameter estimates  
 3 unless all possible factors that could affect on skid resistance are considered. Therefore, careful  
 4 consideration of the unobserved variables is needed. Table 2 shows the all possible factors  
 5 affecting skid resistance found in previous literature and their availability in the data set used in  
 6 this study. Unobservable variables are Polished Stone Value (PSV), aggregate type, lane AADT,  
 7 tester device error, and type of tire used. PSV and aggregate type are attributes of the pavement  
 8 sections. Therefore, their absence can cause a problem of correlation of residuals among  
 9 observations of each pavement section. This problem can be solved by using a random-effects  
 10 panel data model (15) which accounts for the unobservable characteristics of individual  
 11 pavement sections.

12 Lane AADT is an attribute of the lane in which the skid resistance is measured. This is a  
 13 significant variable because the distribution of traffic, especially heavy vehicles, varies across  
 14 lanes. To account for this effect, the location of lane itself (median, middle, or shoulder lane) is  
 15 considered as an explanatory variable. Finally, the unobservable measurement factors such as  
 16 tester device error and type of tire used are assumed random components, which means that they  
 17 are independent and identically distributed.

18 The form of the random effect panel data models used in this analysis is as follows:

19

$$\begin{aligned} \text{Ln}(\text{SN40}_{it}) = & \beta_1 \text{Ln}(\text{TRRAFIC}_{it}) + \beta_2 (\text{LANE}_{it}) + \beta_3 (\text{TEMP}_{it}) + \beta_4 (\text{PRCP}_{it}) + \beta_5 (\text{DP}_{it}) \\ & + \beta_6 \text{Ln}(\text{AGE}_{it}) + \alpha_0 + u_{it} \end{aligned}$$

20

21

22 where  $\text{SN40}_{it}$  = measured skid resistance (skid number) at 40 mph on section  $i$  at time  $t$ ;

23  $\text{TRRAFIC}_{it}$  = traffic condition on section  $i$  at time  $t$ ;

24  $\text{LANE}_{it}$  = dummy variable representing the lane where measurement was taken on section  
 25  $i$  at time  $t$ ;

26  $\text{TEMP}_{it}$  = temperature condition on section  $i$  preceding or at time  $t$ ;

27  $\text{PRCP}_{it}$  = amount of precipitation received at section  $i$  before time  $t$ ;

28  $\text{DP}_{it}$  = the length of dry periods at section  $i$  preceding time  $t$ ;

29  $\text{AGE}_{it}$  = age of pavement on section  $i$  at time  $t$ ;

30  $\beta_i$  = regression coefficients ( $i = 1, 2, \dots, 6$ );

31  $\alpha_0$  = constant;

32  $u_{it} = \varepsilon_{it} + (\alpha_i - \alpha_0)$ ;

33  $\alpha_i$  = random intercept term which varies across sections;

34  $\varepsilon_{it}$  = random term accounting for the unobserved characteristics of section  $i$  at time  $t$ .

35

36 The random term  $u_{it}$  has the following properties;  $E[u_{it}] = 0$ ,  $\text{Var}[u_{it}] = \sigma_\varepsilon^2 + \sigma_\alpha^2$  and  
 37  $\text{Cov}[u_{it}, u_{js}] = 0$  if  $i \neq j$  and  $t \neq s$ ,  $\text{Cov}[u_{it}, u_{is}] = \sigma_\alpha^2$  if  $t \neq s$ , for all  $i, j, t, s$ . Therefore, this  
 38 model can be viewed as a generalized regression model which has parameters  $\beta$  and  $\alpha_0$ . And  
 39 these parameters can be estimated using generalized least squares (GLS).

40 The use of the logarithm of SN40 as the dependent variable is to guarantees that the  
 41 predicted SN40 value is always positive. The choice of this particular form of model was  
 42 primarily based on the findings of previous research. The first explanatory variable,



1  $\text{Ln}(\text{TRRAFIC}_{it})$  accounts for the possible decrease in SN40 with increasing traffic. Therefore,  
 2 the expected sign of  $\beta_1$  is negative. All possible combinations of variables which can represent  
 3  $\text{TRRAFIC}_{it}$  were tested: (a) ADT, (b) truck volume, (c) truck percent and (d) weighted truck  
 4 volume on axles. The logarithm of TRAFFIC was used, to account for the fact that the negative  
 5 effect of traffic is concave. The second variable,  $\text{LANE}_{it}$  accounts for the differences in the mean  
 6 skid number between the median lane and shoulder lane. It is expected that the skid number is  
 7 higher in the median lane and lower in the shoulder lane.  $\text{TEMP}_{it}$  accounts for the possible  
 8 influence of temperature on pavement skid resistance as well as on the measurement device.  
 9 Since it has generally been observed that skid numbers fall with rising temperature, the  
 10 coefficient  $\beta_3$  is expected to be negative. In this analysis, two variables were used to represent  
 11  $\text{TEMP}_{it}$ : (a) temperature at the time of measurement and (b) average temperature over a month  
 12 before the measurement.  $\text{PRCP}_{it}$  accounts for the influence of the precipitation on SN40. Once  
 13 again, more than one parameter was used to represent  $\text{PRCP}_{it}$ .  $\text{DP}_{it}$  accounts for the decrease in  
 14 SN40 with increasing length of the dry period before skid measurement. A number of different  
 15 parameters, including (a) number of dry days since last significant ( $> 2.5$  mm or 0.1 in.)  
 16 precipitation and (b) number of dry months since last significant precipitation, were used in the  
 17 equation for variable  $\text{DP}_{it}$ .  $\text{Ln}(\text{AGE}_{it})$  is used to represent the age effect which is negative. For  
 18 the same reason as  $\text{Ln}(\text{TRRAFIC}_{it})$ , the logarithm function is used.

19 There are two excluded variables among the available variables in Table 2, pavement  
 20 type and test speed. Pavement type is controlled by including only asphalt pavement sections,  
 21 and test speed is not expected to be significant because the measurements were calibrated for  
 22 speed.

23

## 24 ESTIMATION RESULTS

25 Based on the physical characteristics of skid resistance discussed above, the model is estimated  
 26 using LIMDEP software (16), and significant variables were selected. Table 3 shows the selected  
 27 variables and sample statistics of each variable.

28

29

**TABLE 3 Sample Statistics of Selected Significant Variables**

Variable	Units	Mean	Std. Dev.	Minimum	Maximum
SN40		44.32	7.83	6.00	71.00
ADT	1000 vehicle/day	26.49	28.80	3.41	128.00
Dummy for shoulder lane		0.76	0.43	0.00	1.00
Temperature at the time of measurement	F°	63.99	10.16	37.00	108.00
Average precipitation of month	inch	4.00	7.58	0.00	38.65
The number of dry month since the last significant precipitation	Month	0.59	0.96	0.00	4.00
Age	Month	55.89	45.79	1.00	240.00

30

31

**TABLE 4 Estimation Results**

Variable	Coefficient	t-statistic
Constant	4.143	90.540
Ln(ADT)	-0.059	-10.749
Dummy for shoulder lane	-0.121	-14.292
Temperature at the time of measurement	-0.001	-1.712
Average precipitation of month	0.001	2.060
The number of dry month since the last significant precipitation	-0.020	-4.180
Ln(Age)	-0.008	-1.978
Note: Number of observations = 2,848; $R^2=0.70$ ; $L(B)=2263.14$ ; $L(0)=563.87$ .		

The estimated results are shown in Table 4:

- Among all variables related to traffic, ADT is the most significant variable. The coefficient for Ln(ADT) is as expected: SN40 decreases with ADT.
- The coefficient for shoulder lane dummy variable is also as expected: SN40 in the shoulder lane is significantly lower than the average SN40 values due to the distribution of heavy traffic.
- The coefficient for temperature at the time of measurement is significant. The sign of coefficient is intuitive. However, the coefficient is significant at the 90% confidence interval, but not at 95%. This might be due to the time unit of SN40 measurement. The day of measurement is not recorded, and the month of measurement is the most precise time variable available.
- The coefficient of average precipitation of month is significant at the 95% confidence interval, and it has the right sign.
- The coefficient of the number of dry months since the last significant precipitation is significant and has the expected sign: SN40 decreases with the increase of the dry period length.
- The coefficient of Ln(Age) shows that SN40 decreases with the time, which is also expected.

## CONCLUSION

The main objective of this study was to quantify the impact of traffic and environmental effects on skid resistance in California. On the basis of an analysis of SN40 data from 313 miles of asphalt concrete freeways over a period of twenty years, the following conclusions are drawn;

1. There is a significant relationship between SN40 and weather, especially temperature at the time of measurement, average precipitation, and the number of dry months since the last significant precipitation. The combination of these factors can cause seasonal variation in SN40. Therefore, if Caltrans wants to prioritize pavement section maintenance using SN40, the measurements should be standardized. The model presented in this paper can provide the adjustment factors.
2. SN40 is inversely related to ADT, and shoulder lanes tend to have lower SN40 compared with the average due to higher truck traffic. Pavement age has also a negative effect on SN40. However, the effect of ADT and shoulder lane is larger than that of age. This fact leads to the following suggestions for data collecting strategy: SN40 should be monitored

1           intensively at high-risk locations where ADT is higher, and SN40 should be measured in  
2           the shoulder lane to detect possible low values of SN40.

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12

1 **REFERENCES**

- 2 1 *Wet Pavement Safety Programs, National Cooperative Highway Research Program,*  
3 *Synthesis of Highway Practices #158*, Highway Research Board, 1990.
- 4 2 Standards, Designation E274-97, 2004 ASTM Annual Book, 2004.
- 5 3 P.W. Jayawickrama, R. Prasanna and S. P. Senadheera, Survey of State Practices to Control  
6 Skid Resistance on Hot-Mix Asphalt Concrete Pavement, *Transportation Research Record*  
7 1536, TRB, National Research Council, Washington, D.C., pp. 52-58, 1996.
- 8 4 R. Haas, R. Hudson and J. Zaniewski, *Modern Pavement Management*, Krieger Publishing  
9 Company, 1994.
- 10 5 T. Fwa, Y. Choo and Y. Liu, Effect of Aggregate Spacing on Skid Resistance of Asphalt  
11 Pavement, *Journal of Transportation Engineering*, ASCE 129, pp. 420–426, 2003.
- 12 6 W.H. Skerritt, Aggregate Type and Traffic Volume as Controlling Factors in Bituminous  
13 Pavement Friction, *Transportation Research Record* 1418, TRB, National Research Council,  
14 Washington, D.C., pp.22-29, 1993.
- 15 7 W.S. Szatkowski, J.R. Hosking, *The Effect of Traffic and Aggregate on the Skidding*  
16 *Resistance of Bituminous Surfaces*, Transport and Road Research Laboratory, Greta Britain,  
17 TRRL Report LR 504, 1972.
- 18 8 D. A. Anderson, W. Meyers and J. L. Rosenberger, Development of Procedure for  
19 Correcting Skid Resistance Measurements to a Standard End of Season Value,  
20 *Transportation Research Record* 1084, TRB, National Research Council, Washington, D.C.,  
21 pp. 40-48, 1986.
- 22 9 Minh-Tan Do, Zhenzhong Tang, Malal Kane, Francios de Larrard, *Pavement Polishing-*  
23 *Development of a Dedicated Laboratory Test and its Correlation with Road Results,*  
24 *Wear 1–6 Issues*, pp. 36–42, 2007.
- 25 10 P.W. Jayawickrama and B. Thomas, Correction of Field Skid Measurements for Seasonal  
26 Variations in Texas, *Transportation Research Record* 1639, TRB, National Research  
27 Council, Washington, D.C., pp.147-154, 1998.
- 28 11 S. Bazlamit and F. Reza, Changes in Asphalt Pavement Friction Components and  
29 Adjustment of Skid Number for Temperature, *Journal of Transportation Engineering*,  
30 ASCE 131, pp. 470–476, 2005.
- 31 12 Hegmon, R. R. Seasonal Variations in Pavement Skid Resistance—Are These Real? *Public*  
32 *Roads*, Vol. 42, No. 2, pp. 55–62, Sept. 1978.
- 33 13 Bouzid Choubane, Charles R. Holzschuher, and Salil Gokhale, Precision of Locked-Wheel  
34 Testers for Measurement of Roadway Surface Friction Characteristics, *Transportation*  
35 *Research Record* 1869, TRB, National Research Council, Washington, D.C., 2004.
- 36 14 Bouzid Choubane, Charles R. Holzschuher, and Salil Gokhale, and Jim Fletcher, Precision  
37 of Smooth and Ribbed Tire Locked Wheel Testers for Measurement of Roadway Surface  
38 Friction Characteristics, *Transportation Research Record* 1949, TRB, National Research  
39 Council, Washington, D.C., 2006.
- 40 15 R. Ruud, *An Introduction to Classical Econometric Theory*, 2000.
- 41 16 <http://www.limdep.com/products/limdep/>