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16. Abstract

The objective of this study is to identify and evaluate those variables in the vehicle-driver-roadway-weather system that contribute to accidents, with particular emphasis on the friction number. Accident information and skid data are obtained from two computer databases, the Master Accident Listing (MAL) and the Skid Summaries. A total of 94,000 accidents that took place between the years 1982 and 1987 in Tarrant County are analyzed.

An important element in accident studies is the definition and identification of high accident locations. This report proposes a method by which each section of roadway is assigned a relative measure of severity based on the total number of accidents, injuries, and fatalities. The selection is further refined by considering sections with an unusually high number of wet weather accidents.

A major effort was devoted to merging the friction data and accident factors for the selected high accident location. Several problems were encountered that were related to the frequency of skid testing, both in time and space and with respect to the lane and directional distribution. An investigation of the relationship between accidents and friction revealed no definite trend, but it is still unclear whether this finding reflects the truth or is the result of the uncertainties in the friction data. Pure regression analysis and regression with dummy variables were used to identify the most critical types of accidents and to develop an accident prediction equation based upon roadway and weather factors.

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by

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Research Report 490-3

Strategic Research Plan for Achieving Adequate Pavement Friction

Research Project 3-9-86/1-490

conducted for

Texas Department of Transportation

in cooperation with the

U.S. Department of Transportation
Federal Highway Administration

by

CENTER FOR TRANSPORTATION RESEARCH
Bureau of Engineering Research
THE UNIVERSITY OF TEXAS AT AUSTIN

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ABSTRACT

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Key words: Friction Number, High Accident Locations, Accidents, Regression, Dummy Variables

SUMMARY

This study analyzes accident related data and friction data in order to determine and evaluate the variables that influence accidents. A method to identify high accident locations is proposed which is based on the total number of accidents, injuries, and fatalities and on the number of wet-weather accidents relative to the total number of accidents at the section. An attempt was made to merge friction data with accident information at the selected high accident locations. Several problems were anticipated during this procedure, and certain key assumptions had to be made in order to obtain a friction number at the location of the accident. A stepwise regression procedure was carried out in order to identify the significant types of accidents. Regression with dummy variables was used to develop accident prediction models based on roadway, traffic, and weather factors and their probable two-way intersections.

IMPLEMENTATION STATEMENT

The proposed method for selecting high accident locations, which was developed from accident data in Tarrant County, can and should be used to identify high accident locations.

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CHAPTER 1. INTRODUCTION

In September of 1986, the Center for Transportation Research at The University of Texas at Austin was awarded a research contract by the Texas Department of Transportation (TxDOT) entitled "Strategic Research Plan for Achieving Adequate Pavement Friction." The study had two overall objectives:

(1) To investigate the relationship between the aggregate polish value as measured in the laboratory and the frictional resistance actually provided by the aggregate in the field.
(2) To identify and evaluate those variables in the vehicle-driver-roadway system that influence accidents, with particular emphasis on the friction number.

This report describes the work undertaken to carry out the second objective. A preliminary but basic task towards achieving the goals of this study was to evaluate whether existing computer databases which contain information relevant to accidents and pertinent roadway data could easily and systematically be used in accident analyses. There are ample such data available but the format and nature of the data may hinder their appropriate or desired use. More specifically, the possibility of assigning a friction number to specific accident sites will be examined. The commonality basis for retrieving the information from the various databases, the timeliness of accident reports and the conditions of the pavement at the time of an accident, the accuracy of the accident location, and the frequency of friction testing, along with the directional and lane distribution of the data, are key factors to determine the extent to which this task can be achieved. The study will then develop a method for identifying locations of highway segments that are likely to experience higher accident rates than the remainder of the segments in the system under investigation. Having identified these locations, it is then desirable to have complete and accurate information about the vehicle, the driver, the roadway and the environmental factors associated with the specific location. It is imperative to recognize that this procedure not only reduces the data down to a size that will permit comprehensive statistical analyses to be performed, but also assures that the selected pool of sections reflects, at a high degree of certainty, the factors or the interaction of factors that contribute most to accidents. Subsequent statistical analyses will then determine which of the factors are important in explaining the severity of the location.

The two databases that will be used extensively in this report are the Master Accident Listing (MAL) and the Skid Summaries. The first is a computer record of accident data and other related information, while the second contains friction numbers as they are collected by the TxDOT districts. Because of the enormous amount of information available, the decision was made to consider, as a first step, accidents from Tarrant County only, for the years 1982 through 1987, with the possibility of extending the research to other counties as well. Tarrant County was chosen because it includes the metropolitan area and the suburbs of the city of Fort Worth, with a total population of over one million, and can therefore provide a sound statistical sample. In addition to that, the district is one of the few in Texas that collect friction data on a regular basis.

CHAPTER 2. DATABASES

THE MASTER ACCIDENT LISTING (MAL)

In Master Accident Listing[1] is a file containing information on traffic accidents and related roadway data. The accident data is originally coded by the Texas Department of Public Safety (DPS). The Planning Services Section of the D-10 of TxDOT edits the DPS tapes to conform with TxDOT's format and updates the location information. The Safety and Traffic Operations Section of the D-18 of TxDOT then selects specific items from the tapes edited by D-10 and merges the information with roadway data to create the Motor Vehicle Traffic Accident File (MVTA). The MAL is the most commonly generated report from the MVTA file.

Each individual accident in the MAL is coded and referenced by control section and milepoint to the nearest one-tenth mile. A total of fifty variables are included in the MAL, most of which are further subdivided into four to ten items. Some of the variables have up to fifty subitems, which means that the total number of possible variables is very large. In addition, the number of accidents in Tarrant County that were examined in the period between 1982 and 1987 is approximately 94,000. Therefore, reducing the number of variables and accident data to a size that will permit a useful statistical analysis of both the main effects and the interactions is a priority. Regression analysis techniques will be employed to identify those variables that contribute to accidents and to evaluate the relative effect each variable has on the number of accidents. Therefore, the variables selected for consideration should be those that allow changes or improvements to be made on the roadway.

Factors that may influence accidents and provide room for changes to the roadway are the degree of curvature, the alignment of the road, the presence of an intersection and its type, the method of traffic control, and the number of lanes. All these can be used as independent variables in regression analysis.

Based on these considerations, the following variables and sublevels have been identified from the MVTA file and will be investigated in this report.

1. Surface condition
   (a) dry
   (b) wet
   (c) muddy
   (d) snowy/icy
2. Weather
   (a) clear
   (b) raining
3. Number of lanes
4. Degree of curvature
   (a) no curve
   (b) 0.1-1.9
   (c) 2.0-3.9
   (d) 4.0-5.9
   (e) 6.0-7.9
   (f) 8.0-9.9
   (g) 10.0-11.9
   (h) 12.0-13.9
   (i) 14.0-15.9
   (j) 16.0-17.9
   (k) >18.0
5. Alignment
   (a) level
   (b) grade
   (c) hillcrest
6. Intersection-related
   (a) intersection
   (b) intersection-related
   (c) non-intersection
7. Intersection type (intersection at grade)
   (a) not applicable
   (b) three entering roads
   (c) four entering roads
8. Vehicle movements/manner of collision
   (a) two vehicles approaching at an angle
   (b) two vehicles going in the same direction
   (c) two vehicles going in the opposite direction
9. Number of vehicles involved

10. Traffic control
    (a) no traffic control shown or traffic control inoperative
    (b) officer/flagman
    (c) stop and go signal
    (d) flashing red lights
    (e) turn marks
    (f) yield sign
    (g) center stripe or divider
    (h) no passing zone
    (i) other traffic control
11. Number of people injured
12. Number of people killed

SKID SUMMARIES

There are four Skid Summaries available at the TxDOT that provide skid inventory data. Summaries 2, 3, and 4 are computerized and list the low, average, and high friction number for various segments of roads. Each segment could be up to five miles long and, therefore, these numbers have little value in this study because friction numbers are needed at specific accident sites that are one-tenth of a mile long. Skid Summary No. 1 contains the raw data every one-fifth mile, but this information is only available in hard copies. For easy retrieval and manipulation, and in order to avoid mistakes when obtaining the data manually, Skid Summary No. 1 for the years 1984, 1986, and 1988 was entered into a computer database. Each friction location is referenced by control section and milepoint, and this provides the commonality basis for merging with the accident file.

The question of how much influence pavement friction has on accident occurrence is still unanswered. A 1986 study(3) attempts to attribute more than 80 percent of the accidents to human factors, 3 to 5 percent of vehicular characteristics and the remaining 10 to 15 percent to roadway characteristics (with pavement friction being one of them). As reported, this percentage alone represents thousands of accidents, which can be successfully reduced if the actual causes are known and if engineering improvements are applied in a timely manner to the pavement. A recent Synthesis of Highway Practice on wet-pavement safety programs(4) has revealed that all 50 states have an accident-reporting system and a pavement-friction testing program, but only two-thirds of the states have a policy that takes some form of action as a result of friction test results. This happens, however, despite no hard evidence that higher friction can reduce the number of accidents, and despite the fact that many agencies have indicated that they feel there is no relation between friction number and wet-pavement accidents. Everybody works on the premise that a higher friction surface provides better vehicle control than a slick surface by reducing the stopping distance and/or the potential for skidding, and the fact that accident-friction analyses have not proven so yet does not mean the hypothesis is wrong.

The question then arises why the friction number does not appear to be significant in statistical analyses. One probable cause is that accidents are events that are more likely to happen under certain favorable conditions (although this does not imply that, given these conditions, accidents are certain to happen). Also, accidents are unique in the sense that each one can be caused by different factors or by an interaction of factors that have a different effect each time, even if the same location is under consideration. This means that the significance of many factors will be difficult to ascertain in regression analysis because of the different effects they may have in causing the accidents. In addition, there is always the question of including in the analysis all the possible factors that may influence accidents; and, if some are left out for one reason or another, then there is a danger of attributing causes to the wrong factors. Finally, as recognized by many states,(4) there is concern about how many of the accidents reported are located with sufficient accuracy to satisfy the requirements of the researchers who gather and make use of the data.

CHAPTER 3. HIGH ACCIDENT LOCATIONS

DEFINING AND SELECTING HIGH ACCIDENT LOCATIONS (HAL)

In the study of accidents it has been common practice to identify sections of roadway with an unusually high accident occurrence and, through some method of analysis, to establish the cause and to apply an improvement program to correct the problem. What constitutes a high accident location is arguable, but all researchers have the basic agreement that such a location has to have some measure of the accident frequency. As stated earlier accidents are the result of a combination of factors in the driver-vehicle-roadway system, the contribution of these factors to each accident is variable, even at the same location. For example, one study[2] has shown that accident rates increase (up to a certain threshold) as the traffic volume to capacity ratio increases, yet the highest accident rates in the study occurred at night, during hours with the lowest traffic volumes. Furthermore, the nature of the accidents changed from high multiple vehicle accident rates (during the day) to high single vehicle accidents (at night). The study suggests that the above conclusions may not be strong because the analysis was based on forty-four sites that included both two- and four-lane roads but did not consider the number of lanes as a variable. Therefore, proper consideration of all the factors not only influences the outcome of the results of the statistical analyses but also the way a site is assigned a relative severity for selecting high accident locations.

Several methods have been proposed to avoid this problem and to standardize the process of selection, one of which is by incorporating into the accident frequency the number of vehicle passes using the daily traffic and the number of lanes, thus having as a measure the accident rate. Another approach is to analyze sections of roadway with commonalities, like all urban intersections or all roads with the same classification type or service. Accident type offers yet another method (wet versus dry, day versus night, single-vehicle versus multi-vehicle accidents). Finally the relative distribution of accidents within the same stretch of road can be used as a basis for selecting the HAL.

Given these considerations, the selection of HAL in this study will be established by the following factors:

(1) the inference space;
(2) the sample size and period of analysis; and
(3) the sample type.

1. The Inference Space

At the initial stage of the analysis, at least, and before any other direction is undertaken, the data used will represent all the roads on the highway system of Tarrant County. HAL will be generated for roadway sections of 0.1-mile length (approximately 500 feet), irrespective of the type of accident (single- versus multi-vehicle), the presence or absence of intersections, the volume of traffic, etc. The advantage of using such a broad inference space is that it allows the choice of the HAL from a very large pool of sections; this ensures that systematic errors are practically eliminated and that the selected sections are actually the most critical ones. Also, choosing the HAL irrespective of the vehicle-driver-roadway-environment variables offers the potential of evaluating the relative contribution of each of these variables.

2. The Sample Size and Period of Analysis

The selected data represent approximately 94,000 accidents that happened during the period 1982-87 in Tarrant County. High accident locations will be determined from the total number of accidents and persons involved, and the criteria will be modified accordingly to select the required number of locations. The intent is to obtain locations on the order of several hundreds.

Using data that covers a long period of time—six years in this case—is somewhat troublesome because accounting for changes in the driver-vehicle-roadway system is not easy. On the other hand, sections with a consistently high number of accidents per year should, with little doubt, fall into the category of HAL, again minimizing the risk of erroneously selecting a section.

3. *The Sample Type*

The major focus of the analysis will be high accident locations. However, in order to avoid attributing causes to the wrong factors (because of some systematic pattern of the data), other sections will be included in the sample. These will, of course, be lower accident locations which, in some cases, are adjacent to HAL sections.

PROCEDURE FOR IDENTIFYING HAL AND DEVELOPMENT OF AN INDEX

As a first attempt, the MAL file was scanned, and frequency tables were generated for a number of controls and sections. These tables, a sample of which is shown in Tables 3.1 and 3.2, present the total number of accidents, injuries, and fatalities every 0.1 mile for two controls and sections. To avoid giving excessive weight to isolated but severe accidents that involved many injuries and deaths, no more than one injury and one fatality was counted per accident occurrence. The measure of the severity of each/or 0.1 mile section was then calculated as the ratio of the number of injuries and the number of deaths per total number of accidents. Thus, sections would have ratios between 0 and 1, with 1 being most critical. After reviewing the results from several control sections, it was found that the injury ratio tended to over-represent or discriminate in favor of including sections into the HAL list that had only one or two injuries and the same amount of accidents. On the other hand, the death ratio was in most cases zero in spite of the long study period.

A second approach was then tried in which an empirical index number was assigned to each location based on the number of accidents, injuries, and fatalities. Each of these three factors was given increasingly higher importance in the formula:

$$\text{INDEX} = 0.1 * \text{Accidents} + 0.3 * \text{Injuries} + 0.6 * \text{Fatalities}$$

Thus, a fatality carries twice as much weight as an injury and six times more weight than an accident. The index number, shown in the last columns of Tables 3.1 and 3.2, is not limited to any range but the maximum number observed was between 20 and 30.

A HAL was considered to be a location with an index of 5 or more: approximately 10 to 20 percent of the locations per control section were thus included in the HAL list. Furthermore, because the friction number is a major study factor in this investigation, a subsequent refinement of the selection was made by establishing a wet index. This number represents the ratio of the wet-weather accidents to the total number of accidents for the site in question, and ranges between 0 and 1. Tables 3.3 and 3.4 show the respective index and wet index numbers for the two control sections for sites that have indexes greater than 5.

An arbitrary limit of 0.2 was then established which, in conjunction with the index of 5, resulted in final HAL lists that have approximately 2 to 8 percent of the total number of sections retained. For example, control section 80 is 9.9 miles long and is divided into 89 sites. Of those sites, 16 had an index greater than 5, and only 2 had an index greater than 5 and a wet index greater than 0.2. Control section 2208 is 12 miles long and is divided into 116 sites. Twenty-five sections had an index greater than 5 and 10 met the criteria for both the index and wet index.

The inclusion of the wet index in the identification of a HAL is important because it acknowledges the universally accepted notion that low pavement friction does not contribute to accidents unless the pavement is wet. Therefore, sections with an unusually high number of accidents, injuries, and fatalities—as well as an unusually high number of wet-weather accidents—offer the best sample for studying the effect of pavement friction along with the other variables. Tables 3.1 through 3.4 do not show the variables from the MAL but they are retained in the database for future analyses.

One final point that should be made is that a HAL is based on the total number of accidents and persons involved; the index number was not adjusted for daily traffic or number of lanes (to obtain an index rate) because the public is more concerned with the total number of accidents than with the amount of traffic circulation through the section. Also, if a rate was used, locations with many accidents and many lanes or high traffic volume might be treated in the same manner as locations with a few accidents and low traffic volume. On the other hand, if remedial action is applied to a site with many accidents the benefit would be far greater than if it was applied to a HAL that had few accidents, because more accidents could be prevented.

Table 3.1 Accident frequencies by control-section-milepoint (control 80, section 7)

Milepoint	Accidents	Injured	Fatalities	Injured/ Accidents	Fatalities/ Accidents	Index
0.0	1	0	0	0	0	0.1
0.1	2	0	0	0	0	0.2
0.2	9	1	0	0.11	0	1.2
0.5	9	3	0	0.33	0	1.8
0.6	22	3	0	0.14	0	3.1
0.7	24	4	0	0.17	0	3.6
0.8	24	5	0	0.21	0	3.9
0.9	13	6	0	0.46	0	3.1
1.0	14	3	0	0.21	0	2.3
1.1	7	3	0	0.43	0	1.6
1.2	11	2	0	0.18	0	1.7
1.3	37	6	0	0.16	0	5.5
1.4	6	0	1	0	0.167	1.2
1.5	17	5	0	0.29	0	3.2
1.6	73	15	0	0.21	0	11.8
1.7	119	22	1	0.18	0.008	19.1
1.8	121	20	0	0.17	0	18.1
1.9	145	21	0	0.14	0	20.8
2.0	56	17	0	0.3	0	10.7
2.1	14	2	0	0.14	0	2.0
2.2	32	10	0	0.31	0	6.2
2.3	10	3	0	0.3	0	1.9
2.4	14	6	0	0.43	0	3.2
2.5	5	3	0	0.6	0	1.4
2.6	14	3	0	0.21	0	2.3
2.7	15	7	0	0.47	0	3.6
2.8	6	4	0	0.67	0	1.8
2.9	3	2	0	0.67	0	0.9
3.0	9	3	0	0.33	0	1.8
3.1	43	24	0	0.56	0	11.5
3:2	1	1	0	1	0	0.4
3.3	9	3	0	0.33	0	1.8
3.4	8	4	0	0.5	0	2.0
3.5	10	3	1	0.3	0.1	2.5
3.6	16	6	0	0.38	0	3.4
3.7	14	6	0	0.43	0	3.2
3.9	12	3	0	0.25	0	2.1
4.0	8	4	0	0.5	0	2.0
4.1	23	11	1	0.48	0.043	6.2
4.2	16	7	0	0.44	0	3.7
4.3	8	2	0	0.25	0	1.4
4.4	2	0	0	0	0	0.2
4.5	31	8	0	0.26	0	5.5
4.6	22	8	0	0.36	0	4.6
4.7	64	22	0	0.34	0	13.0
4.8	22	10	0	0.45	0	5.2
4.9	5	3	0	0.6	0	1.4

Table 3.1 Accident frequencies by control-section-milepoint (control 80, section 7) (continued)

Milepoint	Accidents	Injured	Fatalities	Injured/ Accidents	Fatalities/ Accidents	Index
5.0	43	22	0	0.51	0	10.9
5.1	20	9	0	0.45	0	4.7
5.2	93	42	0	0.45	0	21.9
5.3	19	8	0	0.42	0	4.3
5.4	31	12	0	0.39	0	6.7
5.5	3	3	0	1	0	1.2
5.6	3	2	0	0.67	0	0.9
5.7	7	4	0	0.57	0	1.9
5.8	4	2	0	0.5	0	1.0
5.9	1	1	0	1	0	0.4
6.1	9	4	0	0.44	0	2.1
6.2	2	1	1	0.5	0.5	1.1
6.3	1	0	0	0	0	0.1
6.4	5	3	0	0.6	0	1.4
6.5	26	13	0	0.5	0	6.5
6.6	4	2	0	0.5	0	1.0
6.7	16	3	0	0.19	0	2.5
6.8	6	4	0	0.67	0	1.8
7.0	1	0	0	0	0	0.1
7.3	1	0	0	0	0	0.1
7.4	4	0	0	0	0	0.4
7.5	4	2	0	0.5	0	1.0
7.6	2	1	1	0.5	0.5	1.1
7.7	10	3	0	0.3	0	1.9
7.8	3	0	0	0	0	0.3
8.0	1	0	0	0	0	0.1
8.2	8	5	0	0.63	0	2.3
8.3	1	1	0	1	0	0.4
8.4	2	1	1	0.5	0.5	1.1
8.6	1	1	0	1	0	0.4
8.7	5	4	0	0.8	0	1.7
8.8	4	2	0	0.5	0	1.0
8.9	3	1	0	0.33	0	0.6
9.0	2	1	0	0.5	0	0.5
9.2	1	1	0	1	0	0.4
9.4	2	1	0	0.5	0	0.5
9.5	2	1	0	0.5	0	0.5
9.6	8	2	0	0.25	0	1.4
9.7	2	2	0	1	0	0.8
9.8	4	1	1	0.25	0.25	1.3
9.9	5	2	0	0.4	0	1.1
10.0	3	1	0	0.33	0	0.6
10.1	3	2	0	0.67	0	0.9
10.2	2	1	0	0.5	0	0.5
10.3	3	1	0	0.33	0	0.6
10.4	3	1	0	0.33	0	0.6
10.5	2	2	0	1	0	0.8
10.7	23	8	0	0.35	0	4.7
10.8	2	0	0	0	0	0.2
10.9	2	1	0	0.5	0	0.5
11.1	1	1	0	1	0	0.4
11.2	4	2	0	0.5	0	1.0
11.3	2	1	0	0.5	0	0.5
11.7	3	1	0	0.33	0	0.6
11.8	2	1	0	0.5	0	0.5

Table 3.2 Accident frequencies by control-section-milepoint (control 2208, section 1)

Milepoint	Accidents	Injured	Fatalities	Injured/ Accidents	Fatalities/ Accidents	Index
10.0	1	0	0	0	0	0.1
10.1	4	1	0	0.25	0	0.7
10.2	14	5	0	0.36	0	2.9
10.3	2	0	0	0	0	0.2
10.4	12	2	0	0.17	0	1.8
10.6	4	1	0	0.25	0	0.7
10.7	3	0	0	0	0	0.3
10.8	6	3	0	0.5	0	1.5
10.9	3	2	0	0.67	0	0.9
11.0	30	10	0	0.33	0	6.0
11.1	5	1	0	0.2	0	0.8
11.2	4	2	1	0.5	0.25	1.6
11.3	6	0	0	0	0	0.6
11.5	2	1	0	0.5	0	0.5
11.6	3	0	0	0	0	0.3
11.9	4	0	0	0	0	0.4
12.0	6	4	0	0.67	0	1.8
12.1	7	1	1	0.14	0.143	1.6
12.2	9	5	0	0.56	0	2.4
12.3	2	2	0	1	0	0.8
12.4	4	3	0	0.75	0	1.3
12.5	2	1	0	0.5	0	0.5
12.6	1	0	0	0	0	0.1
12.7	7	3	0	0.43	0	1.6
12.8	4	2	0	0.5	0	1.0
12.9	5	3	0	0.6	0	1.4
13.0	17	10	0	0.59	0	4.7
13.1	7	5	1	0.71	0.143	2.8
13.2	64	30	1	0.47	0.016	16.0
13.3	3	0	0	0	0	0.3
13.4	4	0	0	0	0	0.4
13.5	2	1	0	0.5	0	0.5
13.6	4	2	0	0.5	0	1.0
13.7	6	3	0	0.5	0	1.5
13.8	9	3	0	0.33	0	1.8
13.9	25	6	0	0.24	0	4.3
14.0	15	6	0	0.4	0	3.3
14.1	51	26	1	0.51	0.02	13.5
14.2	4	2	0	0.5	0	1.0
14.3	5	2	0	0.4	0	1.1
14.4	9	2	0	0.22	0	1.5
14.5	47	18	0	0.38	0	10.1
14.6	3	2	1	0.67	0.33	1.5
14.8	2	2	0	1	0	0.8
14.9	15	3	0	0.2	0	2.4
15.0	45	13	0	0.29	0	8.4
15.1	1	0	0	0	0	0.1
15.2	16	5	0	0.31	0	3.1
15.3	9	1	0	0.11	0	1.2
15.4	94	30	0	0.32	0	18.4
15.5	8	1	0	0.13	0	1.1
15.6	8	2	0	0.25	0	1.4
15.7	22	10	0	0.45	0	5.2
15.8	6	2	0	0.33	0	1.2
15.9	2	1	0	0.5	0	0.5

Table 3.2 Accident frequencies by control-section-milepoint (control 2208, section 1) (continued)

Milepoint	Accidents	Injured	Fatalities	Injured/ Accidents	Fatalities/ Accidents	Index
16.0	14	6	0	0.43	0	3.2
16.1	24	10	0	0.42	0	5.4
16.2	24	9	1	0.38	0.042	5.7
16.3	12	6	1	0.5	0.083	3.6
16.4	113	50	0	0.44	0	26.3
16.5	4	1	0	0.25	0	0.7
16.6	7	2	0	0.29	0	1.3
16.7	4	3	0	0.75	0	1.3
16.8	2	1	0	0.5	0	0.5
16.9	79	26	0	0.33	0	15.7
17.0	8	2	0	0.25	0	1.4
17.1	5	1	0	0.2	0	0.8
17.2	44	16	0	0.36	0	9.2
17.3	32	13	0	0.41	0	7.1
17.4	138	44	0	0.32	0	27.0
17.5	13	4	0	0.31	0	2.5
17.6	9	4	0	0.44	0	2.1
17.7	8	3	0	0.38	0	1.7
17.8	111	46	1	0.41	0.009	25.5
17.9	7	2	0	0.29	0	1.3
18.0	3	1	1	0.33	0.333	1.2
18.1	5	3	0	0.6	0	1.4
18.2	5	3	0	0.6	0	1.4
18.3	12	6	0	0.5	0	3.0
18.4	144	51	1	0.35	0.007	30.3
18.5	17	8	0	0.47	0	4.1
18.6	17	6	0	0.35	0	3.5
18.7	4	1	0	0.25	0	0.7
18.8	3	1	0	0.33	0	0.6
18.9	31	14	0	0.45	0	7.3
19.0	7	4	0	0.57	0	1.9
19.1	78	43	0	0.55	0	20.7
19.2	6	4	0	0.67	0	1.8
19.3	5	3	0	0.6	0	1.4
19.4	132	52	1	0.39	0.008	29.4
19.5	9	5	0	0.56	0	2.4
19.6	9	4	0	0.44	0	2.1
19.7	8	7	0	0.88	0	2.9
19.8	6	3	0	0.5	0	1.5
19.9	36	14	0	0.39	0	7.8
20.0	28	12	0	0.43	0	6.4
20.1	12	4	0	0.33	0	2.4
20.2	31	12	0	0.39	0	6.7
20.3	14	2	0	0.14	0	2.0
20.4	8	6	0	0.75	0	2.6
20.5	25	9	0	0.36	0	5.2
20.6	9	4	0	0.44	0	2.1
20.7	7	1	0	0.14	0	12.0
20.8	49	27	1	0.55	0.02	13.6
20.9	14	9	0	0.64	0	4.1

Table 3.2 Accident frequencies by control-section-milepoint (control 2208, section 1) (continued)

Milepoint	Accidents	Injured	Fatalities	Injured/ Accidents	Fatalities/ Accidents	Index
21.0	9	2	0	0.22	0	1.5
21.1	16	8	0	0.5	0	4.0
21.2	9	1	0	0.11	0	1.2
21.3	12	6	0	0.5	0	3.0
21.4	5	1	0	0.2	0	0.8
21.5	9	2	0	0.22	0	1.5
21.6	85	30	0	0.35	0	17.5
21.7	8	2	0	0.25	0	1.4
21.8	3	0	0	0	0	0.3
21.9	6	4	0	0.67	0	1.8
22.0	6	5	0	0.83	0	2.1

Table 3.3 High accident locations based on index >5.0 (control 80, section 7)

Milepoint	Accidents	Injured	Fatalities	Index	Wet Index
1.3	37	6	0	5.5	0.05
1.6	73	15	0	11.8	0.07
1.7	119	22	1	19.1	0.08
1.8	121	20	0	18.1	0.04
1.9	145	21	0	20.8	0.07
2.0	56	17	0	10.7	0.18
2.2	32	10	0	6.2	0.19
3.1	43	24	0	11.5	0.16
4.1	23	11	1	6.2	0.04
4.5	***31***	***8***	***0***	***5.5***	***0.23***
4.7	64	22	0	13	0.16
4.8	22	10	0	5.2	0.14
5.0	43	22	0	10.9	0.16
5.2	93	42	0	21.9	0.18
5.4	31	12	0	6.7	0.16
6.5	***26***	***13***	***0***	***6.5***	***0.23***

Table 3.4 High accident locations based on index >5.0 (control 2208, section 1)

Milepoint	Accidents	Injured	Fatalities	Index	Wet Index
11.0	30	10	0	6	0.13
13.2	***64***	***30***	***1***	***16***	***0.33***
14.1	***51***	***26***	***1***	***13.5***	***0.27***
14.5	47	18	0	10.1	0.19
15.0	***45***	***13***	***0***	***8.4***	***0.33***
15.4	***94***	***30***	***0***	***18.4***	***0.2***
15.7	22	10	0	5.2	0
16.1	***24***	***10***	***0***	***5.4***	***0.21***
16.2	***24***	***9***	***1***	***5.7***	***0.25***
16.4	***113***	***50***	***0***	***26.3***	***0.26***
16.9	***79***	***26***	***0***	***15.7***	***0.28***
17.2	44	16	0	9.2	0.16
17.3	32	13	0	7.1	0.19
17.4	***138***	***44***	***0***	***27.0***	***0.25***
17.8	***111***	***46***	***1***	***25.5***	***0.41***
18.4	144	51	1	30.3	0.15
18.9	31	14	0	7.3	0.13
19.1	78	43	0	20.7	0.12
19.4	132	52	1	29.4	0.11
19.9	36	14	0	7.8	0.17
20.0	28	12	0	6.4	0.18
20.2	31	12	0	6.7	0.1
20.5	25	9	0	5.2	0.04
20.8	49	27	1	13.6	0.1
21.6	85	30	0	17.5	0.12

CHAPTER 4. ACCIDENT ANALYSIS

RELATIONSHIP BETWEEN ACCIDENTS AND FRICTION NUMBER

Having defined the HAL, an attempt was made to assign a friction number to each location by year. The accident database was scanned and frequency tables were generated for the HAL by control section, milepoint and year. Friction number, construction and test dates and average daily traffic (ADT) data were obtained from Skid Summary No. 1 and were merged with the accident information. A sample of the combined data for four controls is shown in Tables 4.1 through 4.4. The intent of this work was to examine whether changes in friction number had any influence on the yearly number of accidents at the HAL.

Several problems were encountered during this procedure. First, many controls that had accident information were not tested for skid. The opposite was also true, which, coupled with the fact that friction number and ADT data were missing for some years, reduced, to a certain extent, the number of available data.

The friction numbers were supposed to be available every 0.2 miles but it was observed that in many cases they were only available every 0.3 or 0.4 miles. Several times this distance covered two or three HAL's, each with different indices. Since friction numbers were obtained every other year, some form of interpolation in time had to be assumed if numbers were to be assigned for the year in between. Also, interpolation along the road was in most cases necessary so that a number could be assigned to the specific HAL. Many times, as was observed, friction was fairly constant along the road, and interpolated numbers varied by a few points only. But there were cases in which the numbers varied by more than 10 or 15 points between locations; in these cases, interpolation became rather questionable.

Because of the way the HAL's were obtained, most of them are located on high volume roads that have many lanes. Considering that skidding is performed in only one lane and in one direction, interpolated friction numbers may have little resemblance to the actual friction at the site. Also, since there is considerable variation in friction both in direction and for the lane (as was verified from some controls with multiple tests) and since accidents cannot be separated by lane because most friction numbers would be missing, the one skid provided for the whole cross section represents, to say the least, a sketchy picture of the situation.

Table 4.1 *Accident and friction number data for HAL by control-section-milepoint-year (control 80, section 7)*

Milepoint	Year	Accidents	Injured	SN	Construction Date	ADT
4.5	1982	2	2			
4.5	1983	5	1			
4.5	1984	4	0	25	July 1978	12,500
4.5	1985	10	2			
4.5	1986	6	1	44	July 1978	12,500
4.5	1987	4	2			
4.5	1988			38	June 1986	19,800
6.5	1983	5	2			
6.5	1984	3	1	30	July 1978	12,500
6.5	1985	4	2			
6.5	1986	10	6	39	July 1978	12,500
6.5	1987	4	2			
6.5	1988			48	June 1988	19,800

Table 4.2 Accident and friction data for HAL by control-section-milepoint-year (control 2208, section 1)

Milepoint	Year	Accidents	Injured	Fatalities	SN	ADT
16.4	1986	20	8	0	22	18,700
16.4	1987	12	7	0		18,700
16.4	1988				26	18,700
16.9	1982	13	5	0		18,700
16.9	1983	11	1	0		18,700
16.9	1984	16	7	0	16	18,700
16.9	1985	21	8	0		18,700
16.9	1986	14	3	0	23	18,700
16.9	1987	4	2	0		18,700
16.9	1988				20	18,700
17.4	1982	27	9	0		18,700
17.4	1983	23	5	0		18,700
17.4	1984	26	10	0	16	18,700
17.4	1985	17	5	0		18,700
17.4	1986	34	12	0	22	18,700
17.4	1987	11	3	0		18,700
17.4	1988				20	18,700
17.8	1982	23	8	1		18,700
17.8	1983	19	8	0		18,700
17.8	1984	18	7	0	18	18,700
17.8	1985	19	8	0		18,700
17.8	1986	17	6	0		18,700
17.8	1987	15	9	0		18,700
17.8	1988					18,700

An inspection of the corresponding numbers of accidents and friction numbers for several HAL's showed that no safe conclusion can be made regarding the effect of friction on accidents. In many instances the friction jumped by several points between the years 1982 and 1984 while the number of accidents increased. This is an odd situation, the opposite of what is normally expected. Whether the increase in friction is a result of a seasonal effect on the test itself or due to maintenance work not documented in the database is difficult to ascertain. The result is that there are so many uncertainties involved in assigning a friction number to a specific location and so many areas of potential error including testing, reporting, and retrieving data, that the use of friction data in their present form is not recommended.

Undoubtedly, much of the data is accurate and well documented. But when performing statistical analyses it is those oddball data—the outliers—that are given disproportional weight that confounds any potential effects or trends. Therefore, it is suggested that the TxDOT reconsider the design of the skid program so that friction files are adjusted in format and content to serve specific purposes such as accident analysis, and resurface prioritization. In order to accommodate accident analyses skid data should be obtained at the same space intervals as data for accidents. Skid data should also be obtained more frequently, since the two-year periods are not sufficient. Because experience has shown that the recorded data can be erroneous for a variety of reasons, there should be an immediate verification of the data upon collection.

Another key element is how accurately accident locations are reported. The current interval of 0.1 mile (more than 500 feet) is considered too long because friction data and other factors can vary considerably. The TxDOT should adopt a systematic method that will enable researchers to record accidents within 0.01 mile, a recommendation that also appears in Synthesis 158.[4]

Table 4.3 Accident and friction data for HAL by control-section-milepoint-year (control 1978, section 1)

Milepoint	Year	Accidents	Injured	Fatalities	SN	Construction Date	ADT
2.3	1982	8	4	0			
2.3	1983	5	3	0			
2.3	1984	6	3	0	21	October 1978	6,500
2.3	1985	11	7	0			
2.3	1986	7	2	0	19	July 1984	8,200
2.3	1987	4	2	0			
2.3	1988				55	September 1986	11,300
5.2	1982	15	3	1			
5.2	1983	14	8	0			
5.2	1984	16	4	0	23	October 1978	6,500
5.2	1985	8	1	0			
5.2	1986	8	1	0	19	July 1984	8,200
5.2	1987	5	1	0			
5.2	1988				48	September 1984	11,300
6.1	1982	6	3	0			
6.1	1983	9	3	0			
6.1	1984	7	3	0	18	October 1978	6,500
6.1	1985	8	3	0			
6.1	1986	9	6	0	10	July 1984	8,200
6.1	1987	10	5	0			
6.1	1988				52	September 1984	11,300
6.2	1982	11	5	0			
6.2	1983	21	4	0			
6.2	1984	9	6	0	18	October 1978	6,500
6.2	1985	23	8	0			
6.2	1986	29	10	0	10	July 1984	8,200
6.2	1987	31	17	0			
6.2	1988			0	52	September 1984	11,300

Table 4.4 Accident and friction data for HAL by control-section-milepoint-year (control 1330, section 1)

Milepoint	Year	Accidents	Injured	Fatalities	SN	Construction Date	ADT
12.1	1982	6	3	0			
12.1	1983	10	1	0			
12.1	1984	8	2	0	23	July 1968	1,930
12.1	1985	5	3	0			
12.1	1986	7	1	0	20	August 1984	3,170
12.1	1987	10	2	0			
12.1	1988				17	August 1984	6,080
12.5	1982	8	2	0			
12.5	1983	14	1	0			
12.5	1984	13	5	0	25	July 1968	1,930
12.5	1985	18	4	0			
12.5	1986	13	5	0	16	August 1984	3,170
12.5	1987	14	3	0			
12.5	1988				19	August 1984	6,080

RELATIONSHIP BETWEEN THE INDEX NUMBER AND ACCIDENT FACTORS

The second part of the analysis involves statistical regression of the accident locations which are defined by an index number of severity and specific factors related to the site and the conditions during the accident. A total of 15 control sections were selected and the HAL's were determined according to the index and wet-index criteria outlined earlier. Because it was desired that the regression model apply to other, less severe locations as well, sections with indexes between 1.0 and 2.0 were also included in the analysis. This procedure will generate a more global model in addition to recognizing that a specific location analyzed in the future may not be and, in fact, does not need to be a HAL.

The final list included 248 locations. For statistical considerations, the less severe locations were selected so that they would be balanced in number with the HAL's. The following variables were included:

X1 = percent of accidents at intersection
X2 = percent of wet weather accidents
X3 = percent of accidents with vehicles going in the same direction
X4 = percent of accidents with vehicles ap proaching at an angle
X5 = percent of accidents non-intersection-related
X6 = percent of accidents in 3 entering roads (T or Y)
X7 = percent of accidents in 4 entering roads
X8 = number of lanes
X9 = alignment (3 levels: level, grade, hillcrest)
X10 = degree of curve (10 levels)
X11 = average daily traffic
X12 = traffic control with the following 11 levels:

- 0 - no traffic control shown or traffic control in operation
- 1 - officer, flagman, or watchman
- 3 - stop and go signal
- 5 - stop sign
- 7 - flashing red light
- 9 - turn marks
- 11 - warning sign
- 13 - railroad gates or signal
- 15 - yield sign
- 17 - center stripe or divider
- 19 - no passing zone

A stepwise regression model was used in which all the main effects and possible two-way interactions were introduced sequentially into the model if they met a 0.02 significance level criterion. The exact model specified is:

INDEX = X1 X2 X3 X4 X5 X6 X7 X8 X9
X10 X11 X12 ADT
X1*X2 X1*X3 X1*X4 X1*X5
X1*X9 X1*X10 X1*X11 X1*X12
X2*X3 X2*X4 X2*X9 X2*X10
X2*X11 X2*X12
X3*X9 X3*X10 X3*X11 X3*X12
X4*X9 X4*X10 X4*X11 X4*X12
X9*X10 X9*X11 X9*X12
X10*X11 X10*X12
X11*X12

*(The * indicates an interaction of the specified main effects.)*

The purpose of this analysis was to identify the most common types of accidents as they are defined by the geometry of the road (presence or absence of intersection, type of intersection), the weather (wet versus dry surface), and the manner of collision. Each of the variables X1 through X7 represents the percentage of accidents at a location with a given effect expressed as a function of the total number of accidents for the group under consideration. For example, variable X2 is the number of wet-weather accidents divided by the total number of accidents (wet or dry), times one hundred. It should be noted that the number of effects specified in the regression model is the total number in the group minus one in order to avoid collinearity problems.

The summarized results of the analysis are:

Step	Variable Entered	R^2	Significance
1	X1*X3	0.340	0.0001
2	ADT	0.458	0.0001
3	X9*X12	0.501	0.0002
4	X2*X9	0.526	0.0030

The regression model and related statistics are:

	D.F.	Sum of Squares	Mean Square	F	Prob > F
Regression	5	5,605.5	1,121.0	39.74	0.0001
Error	168	4,739.0	28.3		
Total	173	10,344.5			

Variable in Sequence Entered	Parameter	R^2	F	Prob > F
Intercept	2.04455			
X1*X3	0.23635	0.340	61.86	0.0001
ADT	0.000105	0.457	43.26	0.0001
X9*X12	-0.07136	0.500	16.23	0.0001
X2*X9	0.01956	0.526	8.05	0.0051

It can be, therefore, concluded that (a) accidents involving vehicles traveling in the same direction at intersections and (b) accidents involving the interaction of wet weather with the number of lanes are the most critical types of accidents. The complete model explains 53 percent of the severity of a location as it is defined by the index number.

The next step was to generate a regression model that would predict the severity of a location based upon factors that were known prior to constructing a section of road. All the variables which involve the number of accidents were, therefore, excluded from such a model. The variables and the levels used are:

1. Surface condition
   a. S1 = dry
   b. S2 = wet
2. Type of intersection
   a. T1 = non-intersection
   b. T2 = T or Y
   c. T3 = crossing-entering roads
3. Alignment
   a. A1 = level
   b. A2 = grade
   c. A3 = hill crest
4. Traffic Control
   a. C1 = no traffic control
   b. C2 = stop sign/stop and go signal
   c. C3 = yield sign
   d. C4 = divider/center stripe
5. X11 = Degree of curve – 10 levels
6. ADT = Average daily traffic
7. X9 = Number of lanes

The method of dummy variables was used to specify the model; that is, a value of 1 was assigned to the level represented at the accident location, or a value of zero otherwise. Factors 1 through 4 were specified by dummy variables, whereas the rest were treated as interval scale variables. The stepwise procedure was again used, and the complete model is as followed.

INDEX = S1 T1 T2 A1 A2 C2 C3 C4 X9 X11 ADT
ADT*C2 ADT*C3 ADT*C4
X9*S1 X9*T1 X9*T2 X9*A1 X9*A2
X9*C2 X9*C3 X9*C4
X9*X11 X9*ADT X11*ADT

The analysis was carried out with the same 248 accident locations used earlier. Due to missing data, most of which were the ADT, only 166 observations were actually used in the regression equation. Also, for statistical considerations, only five levels of traffic control were used out of eleven. This did not hurt the analysis, in terms of losing a considerable number of data, because only five locations had characteristics related to the six levels that were not considered.

The model generated from the analysis is as follows:

	D.F.	Sum of Squares	Mean Square	F	Prob > F
Regression	4	3,405.4	851.4	22.9	0.0001
Error	161	5,988.8	37.2		
Total	165	9,394.3			

Variable in Sequence Entered	Parameter	R^2	F	Prob > F
Intercept	3.9834			
ADT*C2	0.000155	0.238	51.2	0.0001
ADT*S1	0.00011	0.289	11.8	0.0008
X9*C2	1.66330	0.326	8.9	0.0033
X9*S1	-1.01652	0.363	9.2	0.0029

The developed equation for predicting the severity of a location has the form:

$$\text{INDEX} = 3.984 + 0.000155\ (\text{ADT*C2}) + 0.000106\ (\text{ADT*S1}) + 1.6633\ (\text{X9*C2}) - 1.01652\ (\text{X9*S1})$$

To use this equation, the actual average daily traffic count and number of lanes are substituted for ADT and X9, whereas a number 1 is substituted for a stop sign or dry weather for C2 and S1 respectively, and zero otherwise.

For example, the equation for a dry weather is:

$$\text{INDEX} = 3.984 + 0.000106\ (\text{ADT}) - 1.01652\ (\text{X9}) + 0.000155\ (\text{ADT*C2}) + 1.6633\ (\text{X9*C2})$$

and the equation for wet weather is:

$$\text{INDEX} = 3.984 + 0.000155\ (\text{ADT*C2}) + 1.6633\ (\text{X9*C2})$$

As an example, consider a wet weather condition on a four-lane section of highway with a yield sign as traffic control and ADT = 10,000. The INDEX is equal to:

$$\text{INDEX} = 3.984 + 0.000155 * 10{,}000 * 0 + 1.6633 * 4 * 0 = 3.984$$

If the same stretch of road had a stop sign as traffic control, the INDEX changes to:

$$\text{INDEX} = 3.984 + 0.000155 * 10{,}000 * 1 + 1.6633 * 4 * 1 = 12.187$$

Therefore, considering an INDEX limit of 5 as a HAL criterion, the section has a potential for becoming a high accident location if the traffic control changes from yield sign to stop sign. The opposite is also true.

The results of the analysis indicate that out of 30 main effects and interactions only four are significant to enter into the regression equation. These variables are:

1. Interaction of ADT with a stop sign or stop and go signal
2. Interaction of ADT with a dry surface condition
3. Interaction of number of lanes with a stop sign or stop-and-go signal
4. Interaction of number of lanes with a dry surface condition

These four factors, although significant, can explain only 36 percent of the variance in the index number, and the model is considered relatively weak. This means that unidentified factors explain most of the variance (64 percent).

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

Based on the results from this study, the following conclusions can be drawn:

1. The friction data, as they are presently collected, cannot be reliably, effectively, and confidently used in accident analyses.
2. The reporting of accident locations at 0.1 mile intervals cannot sufficiently represent the specific site characteristics.
3. It is questionable whether friction values interpolated at high accident location sites can accurately reflect the skid resistance of the particular sites.
4. Comparison of accident numbers and friction at high accident locations for the period between 1982 and 1987 revealed no specific relationship or trend between accidents and friction. This finding does not necessarily mean, however, that a relationship does not exist, because of all the uncertainties in the analyzed data.
5. Accidents involving vehicles traveling in the same direction at intersections represent the single most important type of accidents in the data analysed.
6. Out of the 30 factors examined for their contribution to accidents, only the combination of average daily traffic and number of lanes with a stop sign or a stop-and-go signal, or with a dry surface condition were found significant. Despite being significant, the four interactions explain only 36 percent of the variance and the developed model is considered to be rather weak.

RECOMMENDATIONS

If the analysis of accident locations is considered an important priority, then it is recommended that:

1. A more systematic data collection program be devised that will require more frequent testing in terms of space and time, as well as a procedure to identify possible errors in testing, collecting, and recording of data.
2. The index number be used to identify high accident locations.

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