EVALUATING THE POTENTIAL OF REMOTE SENSING RURAL ROAD AND TRAVEL CONDITIONS

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16. Abstract

Communication of current road and travel conditions may potentially reduce the number of accidents attributable to wintertime driving in rural mountain states. The use of real-time remote weather information for updating road and travel information was evaluated. spot speed surveys for different road and travel conditions, road user surveys, snow plow operator reports, and remote weather information system (RWIS) data were analyzed to evaluate the effectiveness of the real-time weather information system. The existing RWIS did not correlate well with the road conditions reported by the road users or snow plow operators. Reliability can be improved by upgrading the RWIS system to include visibility measurement devices, additional sensor locations, and speed monitoring equipment.

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EXECUTIVE SUMMARY[†]

Communication of current road and travel conditions may potentially reduce the number of accidents attributable to wintertime driving in rural mountain states. During the last five years at the study site, 61.1 percent of the total yearly number of accidents occurred during the relatively short time (9.8 percent) that the road and travel conditions were poor. The use of real-time remote weather information for updating road and travel information was evaluated. Spot speed surveys for different road and travel conditions, road user surveys, snow plow operator reports, and remote weather information system (RWIS) data were analyzed to evaluate the effectiveness of the real-time weather information system. The existing RWIS did not correlate well with the road conditions reported by the road users or snow plow operators. Reliability can be improved by upgrading the RWIS system to include visibility measurement devices, additional sensor locations, and speed monitoring equipment.

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CHAPTER 1

EVALUATING THE POTENTIAL OF REMOTE SENSING RURAL ROAD AND TRAVEL CONDITIONS

by

Eugene M. Wilson and Kevin A. French

The number of accidents attributable to winter time driving conditions on the Interstate road system is a significant problem in Wyoming and other mountain states. For the years 1986 to 1991 there was an average of 193 accidents per year on Interstate 80 between the cities of Laramie and Cheyenne, Wyoming (study site). Of those, an average of 118 or 61.1 percent occurred when the roadway conditions were poor (icy, snowy, or slushy). The percentage of time the roadway conditions were poor was estimated at 9.8 percent of the time during those years. A significant portion (61.1 percent) of the total number of yearly accidents occurred during the relatively short time (9.8 percent) that the road and travel conditions were poor.

During this time period, for the study site, the average accident rate for all road users during poor road and travel conditions was 11.63 (number of vehicles involved per 1,000,000 miles of travel). This is about 13 times greater than the accident rate for all road users during favorable road conditions (0.90).

Safety improvements are needed to reduce the number of winter time accidents. One possible solution for addressing the wintertime accident problem is communication of current road conditions. The two main objectives of providing current road and travel information are to provide the road user with information about the severity of the road and travel conditions, and provide the road user with adequate warning so that driving habits can be adjusted accordingly.

This research paper addresses the provision of current road and travel information to road users. There is a potential for using real-time remote weather and traffic information to assist governmental bodies in updating road and travel information. The road and travel information can be communicated to road users using a variety of devices including changeable message signs, road and travel telephone numbers, road and travel information on public radio, and linear radio.

Included in Chapter 2 is a background search of material related to accident analysis, spot speed surveys, and the effects of poor road and travel conditions on road users. Highlights of a survey of state traffic engineers to determine the current usage of remote weather information systems in relation to changeable message signs is also included.

Contained in Chapter 3 are descriptions of the components and methodology employed in the study. The components include the study site, accident data, remote weather information system, speed study site and methodology, road user surveys, and reports of road and travel conditions as reported by Wyoming Transportation Department snow plow operators.

Included in Chapter 4 are the findings of the study. The relationships between the road user, remote weather information system, speed surveys, and the snow plow reports are discussed. Chapter 5 contains a summary of findings, conclusions and recommendations.

CHAPTER 2

LITERATURE REVIEW

Contained in this chapter are literature reviews of materials applicable to the study. First, a literature review of highway safety study procedures are presented which were the basis for the accident analysis. Second, a section is presented concerning the proper procedure for collecting spot speed survey data. Third, a literature review is presented on the effects of poor road and travel conditions on road users. Last, a summary of state traffic engineers, concerning the current usage of remote weather information systems is presented.

HIGHWAY SAFETY STUDY REVIEW

There were 46,300 deaths and a total of 11.5 million accidents involving 19.8 million vehicles occurring on our nation's highways in 1990 (National Safety Council). Safety improvements are needed to reduce the number of fatal, injury, and property damage only motor vehicle accidents. In this research project, highway safety studies were performed to determine the involvement of poor road and travel conditions in accidents occurring on rural interstate highways in mountainous states.

Highway safety studies are used to identify traffic safety hazards and recommend improvements to reduce those hazards. A typical highway safety study consists of the following steps: collecting and analyzing preliminary data, identifying and collecting field data, selecting and performing appropriate studies, evaluating study results, determining safety deficiencies, identifying potential safety improvements, selecting appropriate improvements, and conducting before and after studies to evaluate the effectiveness of improvements (Bowman). A spot speed survey was incorporated into this research to determine the speed effects of poor road and travel conditions on road users.

SPOT SPEED SURVEY

The spot speed survey data were collected using the "time over a distance" or "stop watch" methods. The time required for road users to travel a 199.5-foot course length (distance measured between two delineators) was obtained. Course lengths of about 176 feet for average speeds of less than 40 mph and course lengths of about 264 feet for average speeds greater than 40 mph are recommended (Pignataro).

Due to low traffic volumes, nearly all of the road users were sampled during any given observation period. This method of almost total sampling would be very representative of the actual speed patterns. A minimum sample period of 45 minutes and a minimum sample size of 50 vehicles are recommended to obtain the average speed during the observation period within an error of one-mile-per-hour (Hanscom).

The spot speed survey data were analyzed by first reducing the individual spot speed survey data with the computer program Speed Plot[1]. The variables obtained from

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[1]Bather, Belrose & Boje (BBB) Inc., SPEEDPLOT, Minneapolis, Minn., 1986.

Speed Plot included 50th and 85th percentile speeds, 10-mile-per-hour pace, percent in pace, range of speeds, average speed, and sample size.

The average speed and percent in the 10-mile-per-hour pace were used to analyze the effects of poor road and travel conditions on motorists. Average speed is the average of all spot speeds obtained during observation periods with the same conditions. The percent traveling in the pace is the highest percentage of observed speeds a 10-mile-per-hour group.

The average speeds and percent in pace were compared for different road and travel conditions using regression models. The regression models were developed using the Statistical Analysis Software[2] (SAS) package. Regression models were used to determine the relationship between the predictors (visibility, wind, pavement, and vehicle type) and the dependent variables (average speed and percent in pace).

The regression analysis estimates the best set coefficients for predictors included in the model based on the least squared sums of the residuals. The residuals are the differences between the estimated point values and the actual point values. The coefficient of determination (R^2) is a measure of the adequacy of the regression model and was calculated for each model (Montgomery). Stepwise model building processes were used to determine the most significant predictors affecting the dependent variables.

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[2]SAS Institute, Inc., Statistical Analysis System (SAS), Cary, N.C., 1985.

EFFECTS OF POOR ROAD AND TRAVEL CONDITIONS ON ROAD USERS

There have been many studies documenting the severe effects of poor road and travel conditions on the safety of road users. Poor visibility affects road users by decreasing sight distances to less than that required for adequate stopping sight distance unless vehicle speed is reduced. Strong and gusty winds affect road users by reducing visibility (blowing sand, dust, or snow) and also by buffeting lighter vehicles and high profile vehicles. Poor road conditions affect road users by reducing the coefficient of friction between tires and the pavement surface—increasing stopping distance and decreasing lateral stability in horizontal curves. There are several conditions which cause reduced visibility including fog, rain, snow, dust, and smoke.

Fog, by definition, is a concentration of very small water droplets that is in contact with the ground or very close to the ground (Schwab). Fog has been defined meteorologically to exist when the surface visibility is less than 3,000 feet (Parker). Fog has been found not to affect the average speed of road users until visibility is reduced to less than about 600 feet (Parker). Very dense fogs are dangerous because road users often drive too fast for the available sight distance required for stopping. Fogs, in combination with dry pavement conditions, are much more dangerous that fogs in combination with poor pavements. Road users reduce speeds due to poor pavement conditions. Road users tend to have more confidence in their driving ability and with dry roads do not reduce their speeds during foggy conditions, thereby increasing chances for fog-related accidents.

Snow and rain limit visibility in a number of ways. First, snow flakes and rain drops limit visibility in a similar fashion as fog. Secondly, water (rain or melted snow) on windshields distorts the drivers vision between windshield wiper cycles. Lastly, water (rain or melted snow) on the roadway is splashed or sprayed by passing vehicles, reducing visibility. Dust and smoke also affect road users in a similar fashion as fog.

Snowy or icy pavement conditions present very serious traffic safety problems to road users. The coefficient of friction between tires and wet pavements (used for determining stopping sight distance for the geometric design of highways) is approximately 0.29 at 65 miles per hour (AASHTO). The side friction factor for wet pavement on rural roads is about 0.12 for speeds of 60 miles per hour (AASHTO). The coefficient of friction for icy pavements ranges from 0.05 to 0.20 depending on the condition of the ice—dry, wet, smooth, or rough (AASHTO). The lower friction factor characteristics of icy or snowy pavements require increased stopping distance and also reduce stability in horizontal curves.

Strong and gusty winds often have a detrimental effect on vehicle handling and stability (Parker). Strong and gusty winds affect driver expectancy. Drivers of small cars, vans, campers, and trucks with large cargo surface areas are especially affected as wind speeds and directions change due to bridge abutments and large embankments. Snow and ice conditions compound these problems and cause counter steering measures to compensate for the strong and gusty winds, which may cause road users to lose control of their vehicles.

EXISTING USE OF REMOTE WEATHER INFORMATION SYSTEMS

Several state and local governmental agencies currently use remote weather information systems (RWIS) for maintenance purposes (French). The RWIS is used by several agencies to predict when snow and ice control measures will be required. California, Florida, South Carolina, and Wyoming are a few of the states that have used RWIS for updating or supplementing weather data used to determine the road and travel advisories for road users.

The California Department of Transportation (Caltrans) currently uses RWIS in conjunction with changeable message signing to regulate traffic. Road closure information and expected delays are the types of information (concerning poor road and travel conditions) provided to road users by Caltrans.

The Florida Department of Transportation (FDOT) has used fog detection and warning devices in the past, but these were discontinued due to fog detection device malfunctions. FDOT currently uses wind detection devices and related travel advisories posted on changeable message signs. The South Carolina Department of Highways and Public Transportation currently uses a fog detection and warning system.

The Wyoming Transportation Department (WTD) currently uses remote weather information systems to detect strong and gusty winds on Interstate 80 near Laramie, Wyoming. An automatic wind warning system consisting of a remote wind speed measuring device and changeable message signs is currently being used. Strong and gusty winds are measured and compared to predetermined wind speed criteria. If the wind speed criteria is surpassed, then a high wind warning message is automatically displayed on changeable message signs. The current criteria used by WTD are wind speeds of 35 miles per hour for dry pavement conditions and 25 miles per hour for icy or snowy pavement conditions. The message that is displayed is "WIND GUSTS TO XX MPH — ADVISE NO LIGHT TRAILERS". The accident analysis methodology, spot speed survey procedure and analysis methodology, and an evaluation procedure for the remote weather information system are included in the next chapter of this report.

CHAPTER 3

METHODOLOGY

Contained in this chapter are descriptions of the research components and methodology employed in the study. First, the study site is discussed. Following is a discussion of the methodology for an analysis of winter time accidents. The remaining study components are then described. These components included road user surveys, remote weather information system, speed studies, and reports of road and travel conditions as reported by Wyoming Transportation Department (WTD) snow plow operators. The components of the study are depicted in Figure 3.1, Research Components.

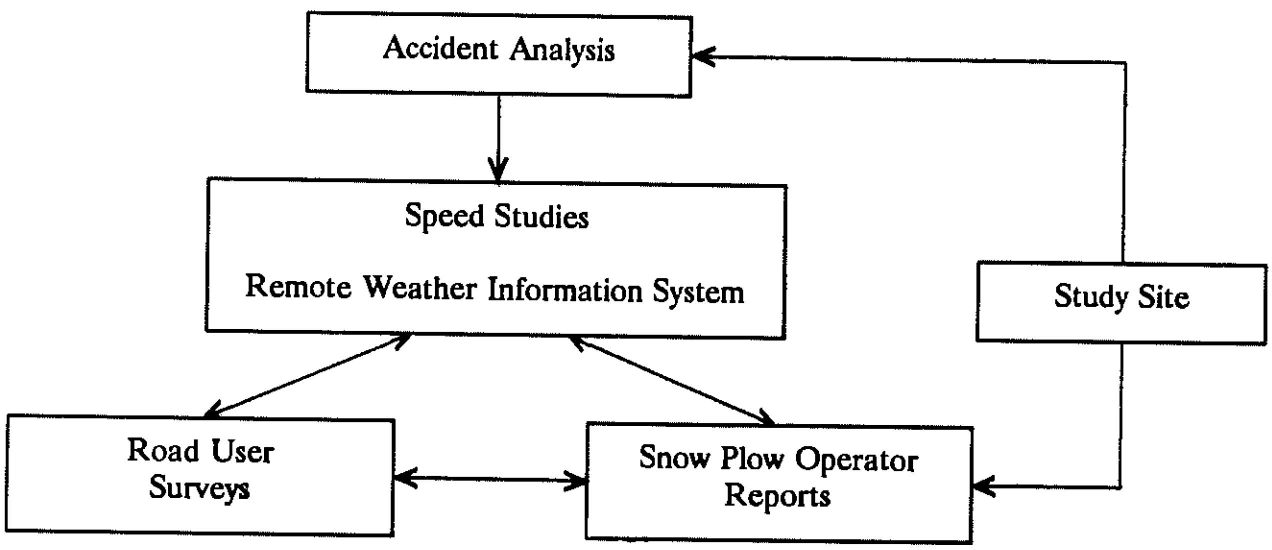


Figure 3.1. Research Components.

STUDY SITE

The study site is located in southeast Wyoming on Interstate 80 between Laramie (Mile Post 317.00) and Cheyenne (MP 358.00). Road and travel conditions vary considerably over the 41 mile section due to changes in elevation, roadway alinement, and adjacent terrain. Due to the non-homogeneous conditions, the study site was broken down into four sections. See Figures 3.2, Vicinity Map and 3.3, Study Site.

Section one is from Laramie to the Lincoln Monument (MP 323.05). The elevation at Laramie is 7,165 feet, rising to an elevation of 8,640 feet at the Lincoln Monument. The difference in elevation is 1,475 feet over the 6 mile distance. The interstate winds through a canyon with grades of up to 10 percent.

Section two runs from the Lincoln Monument to the Buford Exit (MP 335.11). The elevation at the Buford Exit is 7,930 feet, 710 feet lower than the Lincoln Monument. The roadway alignment is generally rolling with a steady decrease in elevation over the 12 mile distance from the Lincoln Monument to the Buford Exit. The surrounding terrain is generally open with few wind obstructions.

Section three extends from the Buford Exit to the Harriman Road Exit (MP 342.56). The elevation at the Harriman Road Exit is 7,458 feet, 472 feet lower than the Buford Exit.

The roadway alignment is generally rolling with a steady decrease in elevation over the 7.5 mile distance from the Buford Exit to the Harriman Road Exit. The surrounding terrain is primarily rolling hills.

Section 4 runs from the Harriman Road Exit to Cheyenne. The elevation at Cheyenne is 6,062 feet, about 1,400 feet lower than the Harriman Road Exit. The roadway alignment is generally rolling with a steady decrease in elevation over the 16.5 mile distance.

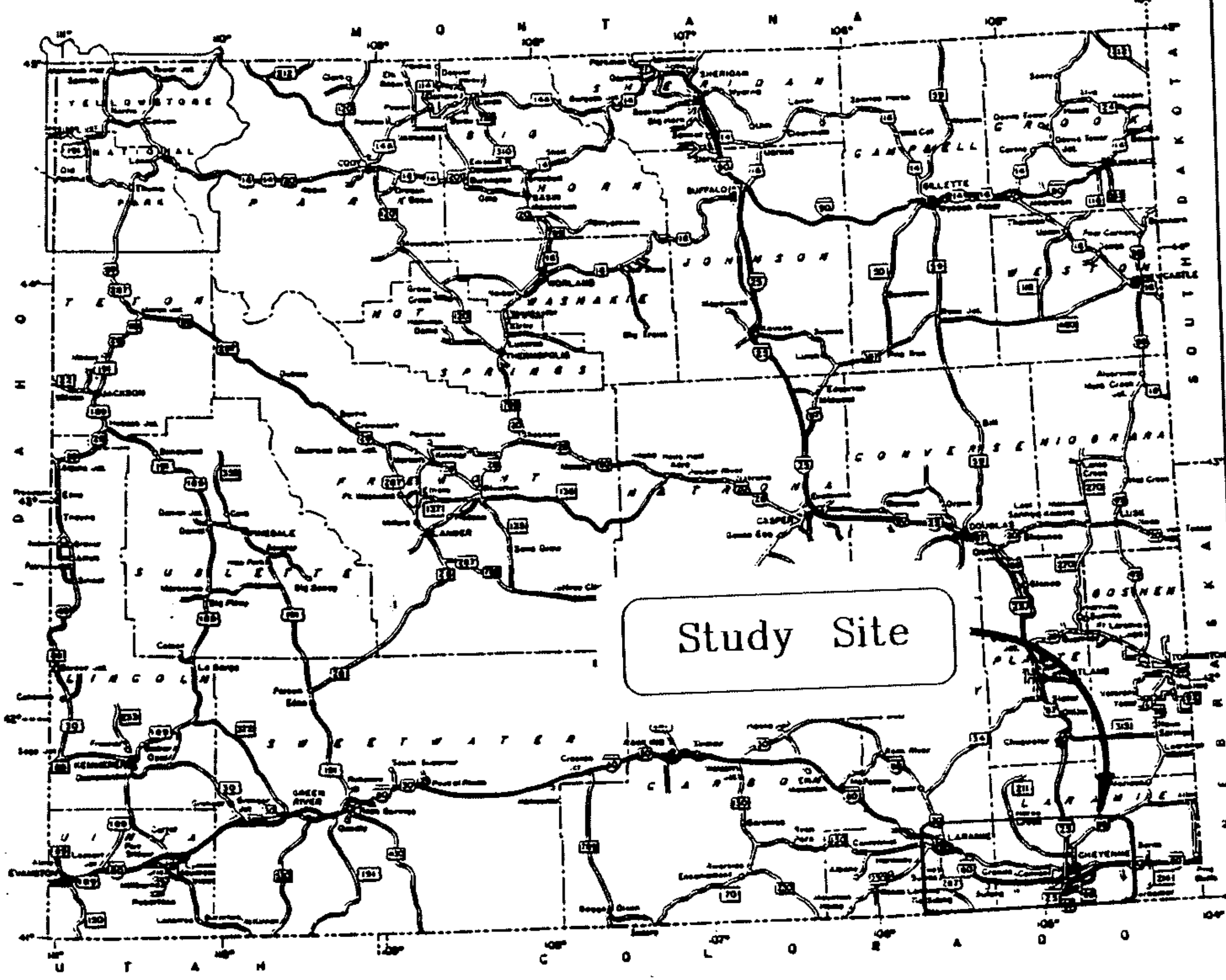
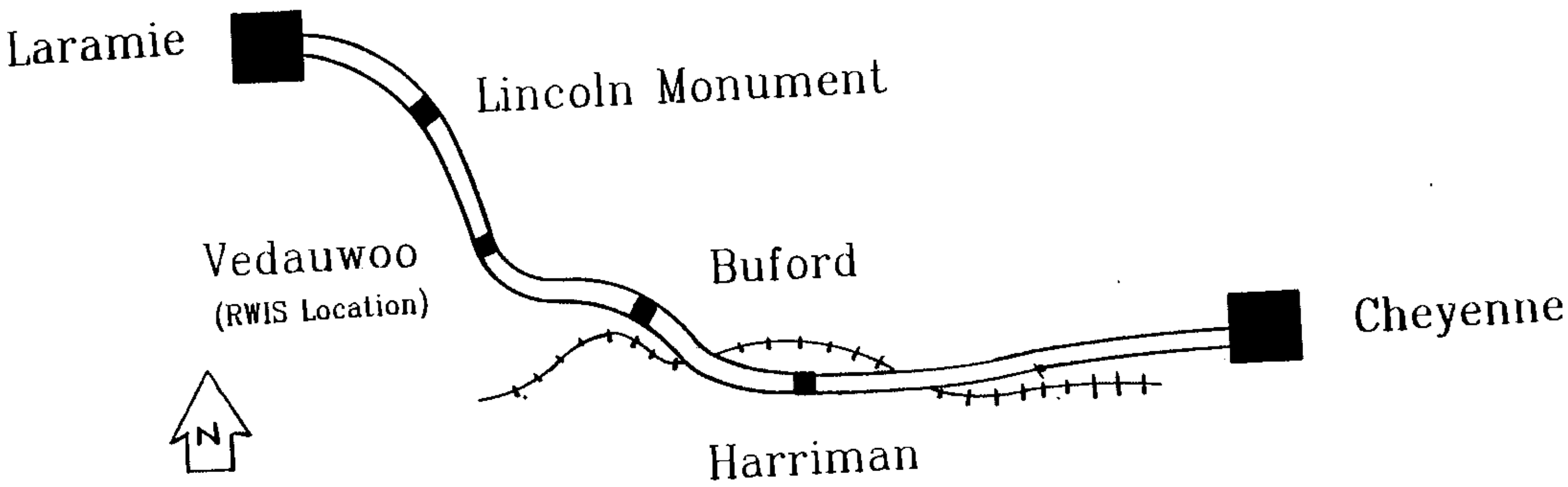


Figure 3.2. Vicinity Map.



	Mile Post	Elevation
Laramie	316.70	7165
Lincoln Monument	323.05	8640
Vedauwoo	329.32	8200
Buford	335.11	7930
Harriman	342.56	7458
Cheyenne	359.08	6062

Figure 3.3. Study Site.

ACCIDENT ANALYSIS

As indicated previously, the number of accidents attributable to wintertime driving conditions is a significant problem in Wyoming and other mountain states. The accident data on Interstate 80 between Laramie and Cheyenne were evaluated to determine trends in winter time accidents. Accident rates for favorable and unfavorable road conditions were estimated for local Wyoming, other Wyoming, and out-of-state passenger vehicles and trucks. Traffic volume data, vehicle classification data, snow/ice maintenance data, and accident data were utilized to estimate the accident rates. The total number of accidents occurring during favorable and unfavorable weather conditions was also tabulated.

Epidemiological accident data were obtained from the WTD for accidents occurring on the 41 mile section between Laramie and Cheyenne for the years 1986 to 1991. Each accident was classified in groups according to vehicle type, driver proximity, and road condition. Traffic volume data were also obtained from the WTD for Interstate 80 between Laramie and Cheyenne.

Vehicle classification studies were performed during weekdays on Interstate 80 between Laramie and Cheyenne near the Vedauwoo Road Exit located approximately 13 miles east of Laramie. Over 3,600 vehicles traveling on Interstate 80 were classified according to vehicle type and driver proximity. Each vehicle was classified as either passenger vehicle or truck. The driver proximity was estimated using the license plate of the vehicle in question. The driver proximity was separated into three categories—local Wyoming, other Wyoming, and out-of-state. Motorists were considered to be local Wyoming if their license plates were from Albany County (County Number 5) or

Laramie County (County Number 2). Road users were considered to be other Wyoming if they had Wyoming license plates from counties other than Albany County or Laramie County. Road users were considered out-of-state if they did not have Wyoming license plates on their vehicles.

The number of hours that the roads were closed by month from 1986 to 1991 was obtained from the WTD. The number of monthly man hours required to control snow and ice on the 41 mile section of Interstate 80 was also obtained from the WTD for the years 1986 to 1991.

The percentage of time that the road conditions were poor from 1986 to 1991 was estimated based on the number of maintenance man hours required to control snow and ice.

A ratio of poor road and travel conditions to snow maintenance hours was determined for similar months in 1991. The year was broken down into four groups of similar months, based on the similarity of weather patterns during those months. The first group included the months of January, February, November, and December. During those months the temperatures are colder than other months and falling and blowing snow would not be as likely to stick to the roadway. Lower daytime temperatures would also lead to snow accumulation on the ground and increase the potential for blowing snow.

The second group included the month of March. During that month there is a higher potential for blowing snow than other months because snow has accumulated on the ground during the previous four cold winter months. High winds and warmer temperatures during the day melts blowing snow onto the roadway. Cold winds blowing across the melted snow or falling temperatures at night freezes the melted snow, causing icy conditions. Falling snow would also be more of a problem because it sticks to the roadway and accumulates.

The third group included the months of April, May, September, and October. During these months there was less accumulated snow than other months which reduces the potential for blowing snow. Poor road conditions were typically the result of passing snowstorms which last for short durations. The conditions may be treacherous during these months since the snow tends to melt onto the roadway during the day and then falling temperatures at night freeze the melted snow on the roadway. These conditions usually exist after the sun sets when the roads are still wet from a storm that occurred during the day.

The last group included the months of June, July, and August. It was assumed the number of hours that the road conditions would be poor due to snow and ice was negligible.

The percentage of time that the road conditions were poor on Interstate 80, between Laramie and Cheyenne in 1991, was estimated using the following procedure. The total number of hours that the road conditions were poor was obtained from the daily snow plow operator reports. The total number of hours the Interstate was open for 1991 was determined by subtracting the number of hours the roadway was closed from the total number of hours in 1991. The percentage of time the road conditions were poor for 1991 was determined by dividing the total number of hours the road conditions were poor in 1991 by the total number of hours the interstate was open in 1991.

The percentage of time that the road conditions were poor for each year from 1986 to 1990 was estimated using the following procedure. The number of hours that Interstate 80 was closed between Laramie and Cheyenne each month of the year was subtracted from the total number of hours in each month to find the total number of hours that the interstate was open. The appropriate group month ratio as described earlier was applied to the number of maintenance hours required for a particular month to estimate the number of hours that the road conditions were poor for that month. The total number of hours the road conditions were poor and the total number of hours the roads were open was found for each year. The percentage of time that the road conditions were poor was found by dividing the total number of hours that the road conditions were poor by the total number of hours that the interstate was open.

The percentage of time the road conditions were poor was plotted against the number of hours required for snow/ice maintenance, see Figure 3.4, Road Condition Percentage—Hours of Snow/Ice Maintenance. As the figure, indicates there was a very good relationship between the two variables resulting in a coefficient of determination (R^2) of 0.89.

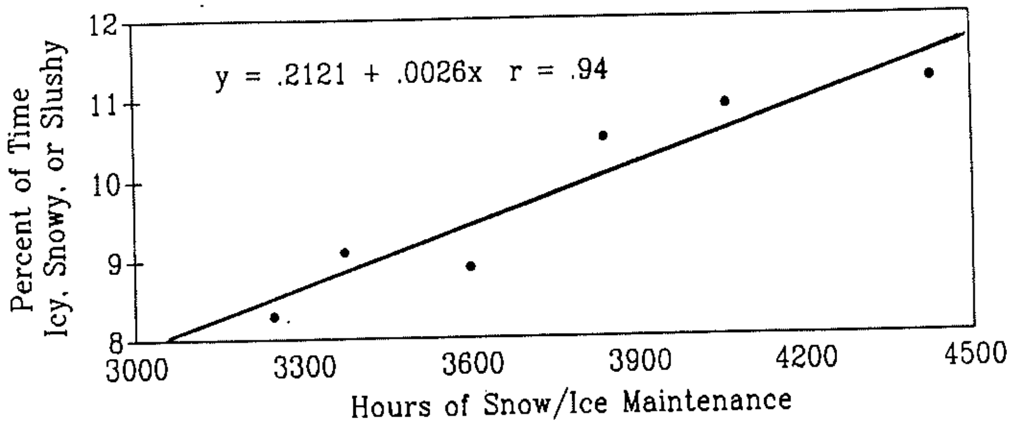


Figure 3.4. Road Condition Percentages versus Hours of Snow/Ice Maintenance.

The vehicles that were involved in accidents for each year from 1986 to 1991 as reported in WTD accident data were classified into groups according to vehicle type, driver proximity, and pavement condition. The vehicles involved in the accidents were classified as passenger vehicle or truck. The motorists driving the vehicles were classified as local Wyoming (County 2 or County 5), other Wyoming (other than County 2 or County 5), or out-of-state. The pavement conditions of the accidents were divided into two groups—dry or wet and icy, snowy, or slushy.

The accident rate (number of vehicles involved in accidents per million miles of travel) by year was calculated for each combination of vehicle type, driver proximity, and pavement condition. First, the average annual daily traffic (AADT) was determined from the traffic volume data for each year. Then the vehicle classification percentages were applied to the AADT to estimate the portion of the AADT represented by each road user group. The percentage of time that the pavement conditions were dry or wet and icy, snowy, or slushy was then used to determine the accident rates for each roadway condition.

The following formula was used to determine accident rates:

$$\textit{Accident Rate} = \frac{\textit{Number of Vehicles Involved} * 1{,}000{,}000}{AADT * VCP * RCP * \textit{Distance}(41\,\textit{miles}) * 365}$$

Where: AADT = Average Annual Daily Traffic
VCP = Vehicle Classification Percentage
RCP = Roadway Condition Percentage

The above procedure was used to determine the accident rate for each road user group for different road and travel conditions. The accident analysis is also a measure to evaluate the effectiveness of any recommendations.

SPEED SURVEYS

Speed surveys were incorporated to determine how varying degrees of visibility, wind, and pavement conditions affect road user behavior during periods of poor road and travel conditions due to adverse weather.

The speed surveys were performed on Interstate Route 80 at the Vedauwoo Road Exit. In the vicinity of the speed surveys, the roadway has two lanes in each direction separated by a depressed median. The geometric layout of the eastbound lanes on Interstate Route 80 in the vicinity of the speed surveys is a slight downgrade of about

0.05 percent and is located on a sweeping horizontal curve. See Figure 3.5, Speed Survey Site. The speed surveys were taken for eastbound traffic and separated into two categories—passenger vehicles and trucks.

As discussed in Chapter 2, the stop watch method of measuring time over a distance was used to determine the spot speeds. The time required for motorists to traverse a 199.5 feet section of roadway marked by two delineator poles was measured. An inconspicuous vantage point was chosen that would allow both delineators to be seen at nearly perpendicular angles to reduce parallax error. The time measurements were converted from number of seconds per 199.5 feet to miles per hour.

The weather-related road and travel conditions were determined as the speed surveys were being conducted. Speed surveys were recorded by time and a combination of visibility, wind, and pavement conditions.

The visibility condition was classified as either clear, limited, or very limited. The visibility condition was considered clear if there was at least 1,200 feet of sight distance. An estimated 1,150 feet of stopping sight distance is required for road users to stop on icy roads based on a friction factor of 0.15 and a travel speed of 65 miles per hour. It was assumed that if the road user had adequate sight distance to safely stop on icy roads, visibility would have no effect on the motorist's speed.

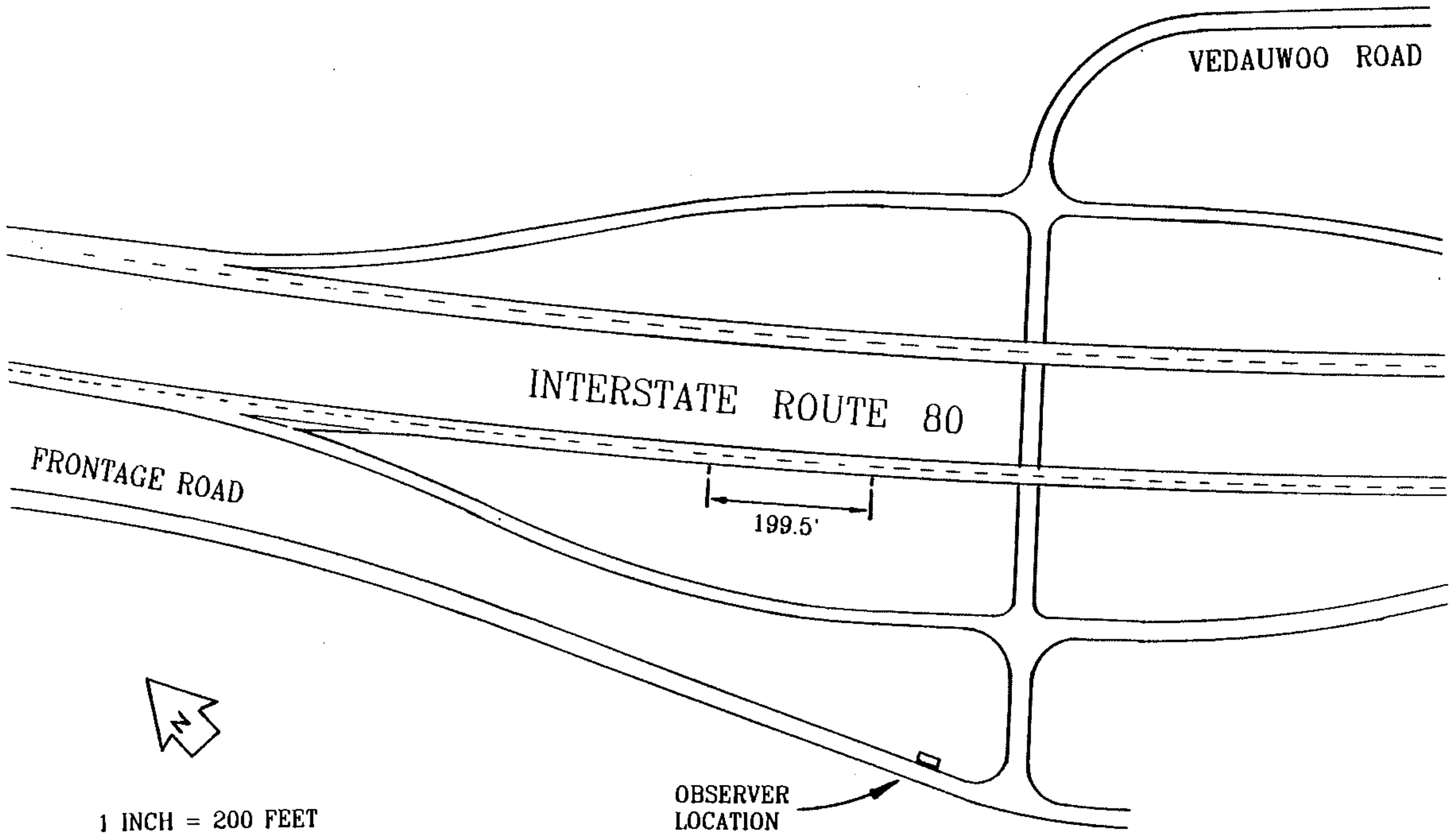


Figure 3.5. Speed Survey Site.

The visibility condition was classified as limited if the available sight distance was between 1,200 feet and 600 feet. An estimated 600 feet of stopping sight distance is required for road users to stop on wet roads if they are traveling at a speed of 65 miles per hour. It was assumed that if a motorist had at least 600 feet of sight distance on dry or wet roads, the limited visibility condition would not affect the road user's speed. If the pavement condition was slushy, snowpacked, slick in spots, or icy, the limited visibility condition may have affected the road user's speed.

The visibility condition was classified as very limited if less than 600 feet of sight distance was available. That condition would require motorists to slow down even on dry or wet pavements in order to maintain a safe stopping sight distance.

The wind condition was classified as either calm or strong and gusty. The wind condition was classified as strong and gusty if the wind was strong enough to buffet the research personnel's vehicle. It was assumed that if the research personnel's vehicle was being buffeted while stationary, the wind would have an appreciable effect on road users driving on the roadway.

The pavement conditions were classified as dry, wet, slushy, snowpacked, slick in spots, or icy. The pavement condition was checked at regular intervals during each observation period.

REMOTE WEATHER INFORMATION SYSTEM

Real-time weather data from a remote weather information system (RWIS) were collected from December 1990 to January 1992. The RWIS is located at the Vedauwoo Road Exit approximately 13 miles east of Laramie on Interstate Route 80 in section two of the study site.

The core of the RWIS system is a surface sensor and a set of atmospheric condition sensors. The output from each of the sensors is fed to a microprocessor called a Remote Processing Unit (RPU) which converts the output into identifiable conditions and then stores the conditions in memory. The measured weather data recorded by the RPU include presence of precipitation, surface pavement temperature, air temperature, relative humidity, wind speed, and wind direction. The RPU then determines the pavement status and dew point based on the measured parameters. All of the data are updated when a predetermined significant change is measured for any one of the seven parameters.

ROAD USER SURVEYS

Questionnaires were designed to obtain road user information concerning road and travel conditions. Road users were asked to complete questionnaires when they had completed a trip between Laramie and Cheyenne. The questionnaires were used to obtain road user characteristics along with the road and travel conditions concerning visibility, wind, and pavement conditions.

Different forms of the questionnaire were targeted toward different road user groups. Travel diaries were designed for regularly commuting road users. Interviews to be completed by research personnel were designed to target interstate and in-state (non-commuter) road users. Postage-paid postcards were designed to be a shortened version of the interviews that could be filled out independently by road users.

Regular commuters were solicited by research personnel using newspaper announcements, fliers, and direct telephone conversation for participation in the study. Once a regular commuter had agreed to take part in the study, a travel diary was sent to the commuter. Commuters consisted mainly of employees and students associated with the University of Wyoming and governmental employees in Cheyenne. Approximately 450 diaries were sent out and 147 where returned by 131 participants. Almost 1,200 diary entries, each representing a single trip between Laramie and Cheyenne, were obtained from the travel diaries.

Two approaches were used to solicit interviews from interstate and in-state (non-commuter) road users. First, WTD research personnel attempted to collect interviews of interstate and in-state road users at truck stops located in Laramie and Cheyenne during poor road and travel conditions. Road users were approached as they entered the truck stops and were asked if they had just traveled westbound from Cheyenne or Laramie on Interstate 80. If the road user had traveled through the study site then interviews were conducted. If the road users were planning to travel on Interstate 80 through the study site, they were given postcards to fill out after reaching Cheyenne or Laramie. This method met with limited success since there are several truck stops located in Laramie and Cheyenne and not all road user frequented these locations.

The second approach of obtaining interviews was by citizens band (CB) radio. WTD personnel parked along Interstate 80 and collected interviews using CB radio. This method was very effective as many of the passing truck drivers were interviewed. A major concern was that truck drivers were the only road users that were interviewed in this manner since most passenger cars do not have CB radios.

In addition to postcards distributed at truck stops, the postcards were displayed in restaurants and gas stations in Laramie and Cheyenne. Road users who frequented participating establishments picked up postcards and filled them out after their trips. This method met with limited success as over 800 postcards were distributed and only 57 were returned for a return rate of about seven percent.

Postcards were also distributed during University of Wyoming home basketball games. Postcards along with fliers explaining the purpose of the research project were placed on vehicles with Cheyenne (county two) license plates, assuming that they were from Cheyenne and that they would travel through the study site during their return trip. Over 600 postcards were distributed during four home basketball games and 107 were returned for a return rate of nearly 18 percent.

SNOW PLOW OPERATOR REPORTS

Information concerning road and travel conditions was obtained from the WTD for all four sections in the study site from December 1990 to January 1992. Snow plow operators described road and travel conditions in terms of visibility, wind, and pavement conditions to radio dispatchers. The radio dispatchers kept a log of road and travel conditions by date and time of day. The road and travel conditions were chosen from a matrix of 36 different combinations of visibility condition, wind condition, and pavement condition, see Figure 3.6, Combination of Conditions—Cell Blocks. The visibility condition was either clear, limited, or very limited. The wind condition was either calm or strong and gusty. The pavement condition was either dry, wet, slushy, snowpacked, slick-in-spots, or icy. Road and travel conditions were updated as conditions changed.

DISPATCHER CODE SHEET

Visibility	Wind	Pavement	Code
CLEAR	CALM	DRY	1
		WET	2
		SLUSHY	3
		SNOW PACKED	4
		SLICK IN SPOTS	5
		ICY	6
	STRONG & GUSTY	DRY	7
		WET	8
		SLUSHY	9
		SNOW PACKED	10
		SLICK IN SPOTS	11
		ICY	12
LIMITED	CALM	DRY	13
		WET	14
		SLUSHY	15
		SNOW PACKED	16
		SLICK IN SPOTS	17
		ICY	18
	STRONG & GUSTY	DRY	19
		WET	20
		SLUSHY	21
		SNOW PACKED	22
		SLICK IN SPOTS	23
		ICY	24
VERY LIMITED	CALM	DRY	25
		WET	26
		SLUSHY	27
		SNOW PACKED	28
		SLICK IN SPOTS	29
		ICY	30
	STRONG & GUSTY	DRY	31
		WET	32
		SLUSHY	33
		SNOW PACKED	34
		SLICK IN SPOTS	35
		ICY	36

Figure 3.6. Combination of Conditions—Cell Blocks.

Snow plow reports were available for nearly all of the days that had poor road and travel conditions. Snow plows are out on the roads for all forecasted storms and are also called out on the request of highway patrolmen and/or maintenance personnel.

During some storms the snow plow reports were not completed. For completeness, snow plow reports were filled out by WTD personnel based on WTD logs that are kept during storms.

The relationships between the components of the study were analyzed and the results are included in Chapter 4, Findings. First, the relationship between the remote weather information system (RWIS) and the road user surveys is presented. Following this is the relationship between the RWIS and the snow plow reports. Last, the relationship between the road user surveys and the snow plow reports is discussed.

CHAPTER IV

ANALYSIS AND RESULTS

This chapter includes the findings of the accident analysis and speed surveys. The relationships between the remote weather information system (RWIS) and speed surveys, road user surveys, and snow plow reports are discussed.

ACCIDENT ANALYSIS

An analysis of accidents occurring on Interstate 80 between Laramie and Cheyenne was performed as discussed in Chapter 3. Traffic volume data obtained from the WTD are illustrated in Figure 4.1, Traffic Volume Data. Traffic increased at approximately eight percent from 1986 to 1988 and at about three percent from 1988 to 1991.

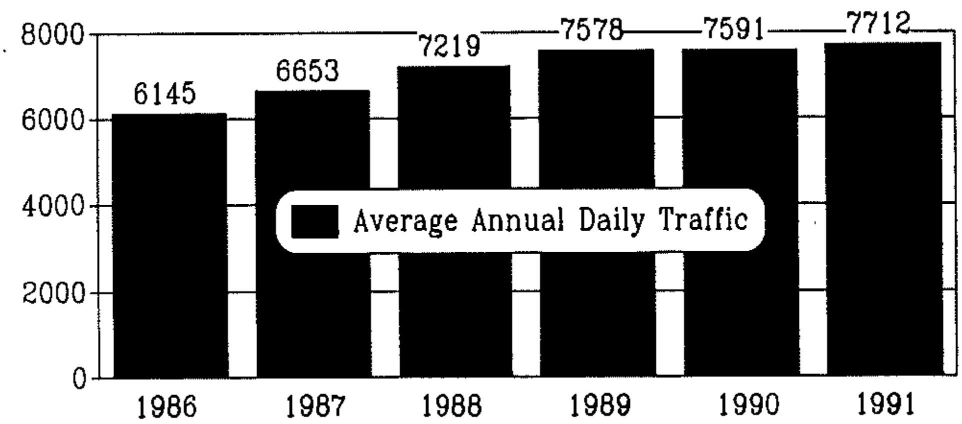


Figure 4.1. Traffic Volume Data.

The vehicle classification data that were collected, as described previously, are depicted in Figure 4.2, Vehicle Classification Data. Out-of-state passenger vehicles and trucks accounted for 58.6 percent of the traffic on Interstate 80 between Laramie and Cheyenne. Local passenger vehicles were an additional 31.3 percent of the traffic.

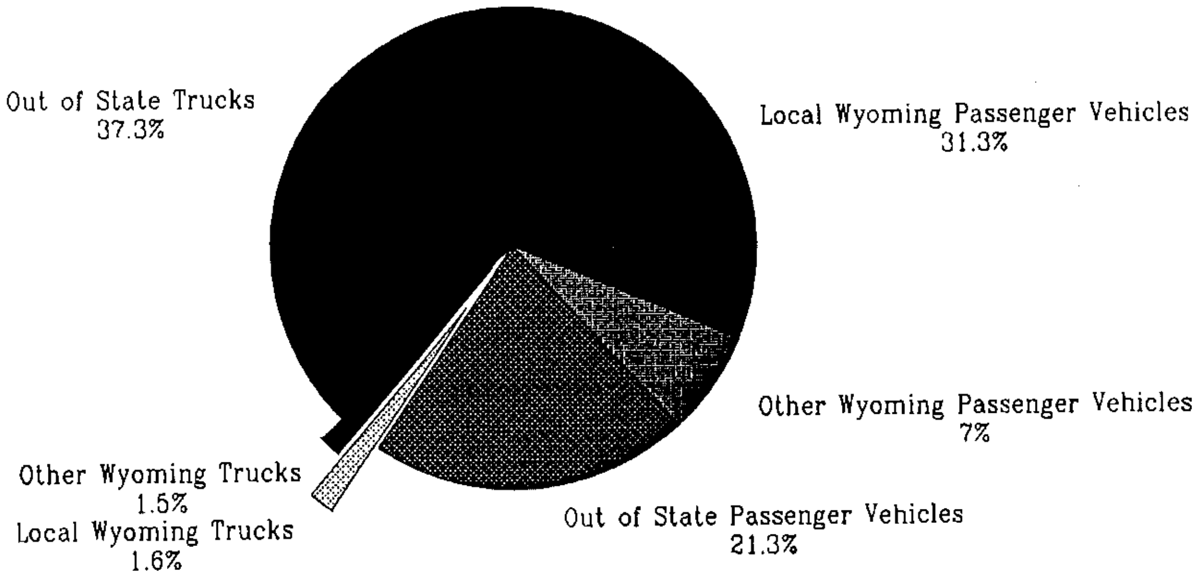


Figure 4.2. Vehicle Classification Percentages.

The road condition data were estimated as described in Chapter 3 and are illustrated in Figure 4.3, Estimated Road Condition Percentages. The average time that the road conditions were poor from 1986 to 1991 was estimated to be 9.8 percent.

The average accident rate for out-of-state road users was 19.04 (number of vehicles involved per 1,000,000 miles of travel) during poor road conditions. This was higher than the

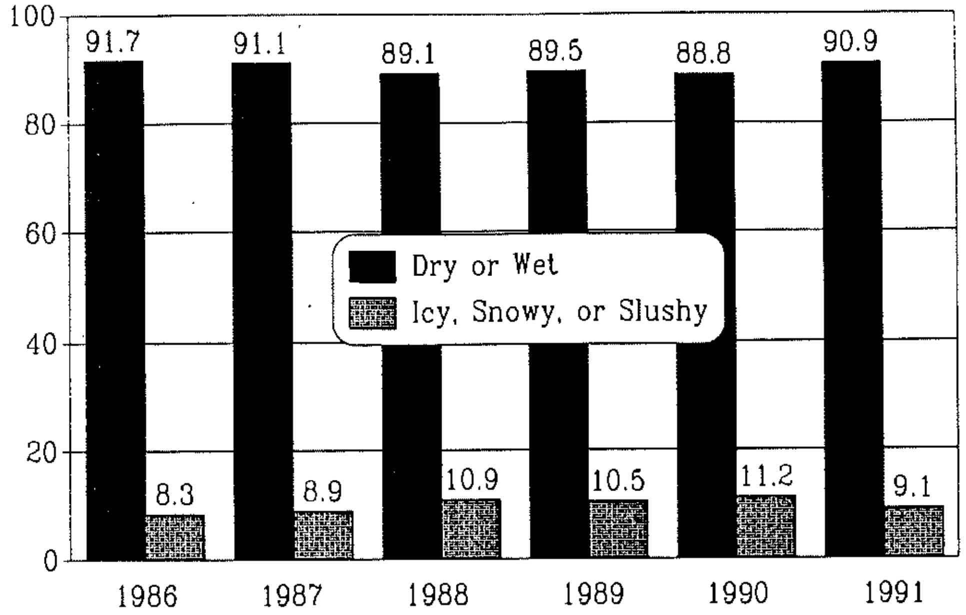


Figure 4.3. Estimated Road Condition Percentages

average accident rate for local Wyoming road users, which was 12.57 during poor road conditions. The accident rates for local Wyoming road users in poor road conditions is 10 to 25 times higher than for favorable conditions.

The accident rate (number of vehicles involved in accidents per million miles of travel) by year was calculated for each combination of vehicle type, driver proximity, and pavement condition using the methodology described in Chapter 3. The rates are listed in Table 4.1, Estimated Accident Rates.

As shown in Table 4.1, the accident rates for road users during poor road conditions were much higher than accident rates for road users during favorable road conditions for all combinations of vehicle type and driver proximity.

Table 4.1. Estimated Accident Rates.

Year	Dry or Wet			Icy, Snowy, or Slushy		
	Local Wyoming	Other Wyoming	Out of State	Local Wyoming	Other Wyoming	Out of State
Passenger Vehicles						
1986	0.61	1.36	1.78	11.30	3.74	14.76
1987	1.16	0.47	2.28	15.50	3.22	27.02
1988	1.03	0.45	2.19	15.19	8.49	19.93
1989	1.04	0.14	1.39	10.46	12.00	23.66
1990	0.95	0.28	1.35	7.53	5.61	23.25
1991	0.49	0.68	1.39	12.47	9.52	28.16
Trucks						
1986	0.00	0.00	0.38	8.19	0.00	12.64
1987	2.76	0.00	0.71	21.16	0.00	15.43
1988	3.25	0.69	0.92	31.85	0.00	17.53
1989	0.62	0.00	0.61	5.25	0.00	20.49
1990	0.62	0.00	0.77	0.00	5.24	9.48
1991	1.19	0.00	0.79	11.90	0.00	16.08

Note: Accident rates are number of vehicles involved in accidents per 1,000,000 miles of travel.

The average accident rate for passenger cars was 1.06 for favorable road conditions and 13.99 for poor road conditions. The average accident rate for trucks was 0.74 for favorable road conditions and 9.74 for poor road conditions.

The number of accidents that occurred during dry or wet and icy, snowy, or slushy conditions were also tabulated for the years 1986 to 1991 and are depicted in Figure 4.4, Number of Accidents. The yearly number of accidents when the road conditions were poor was about 60 percent higher than the yearly number of accidents when road conditions were favorable. The accidents that occurred during poor road conditions happened in a time span that amounted to approximately ten percent of the total time during the year.

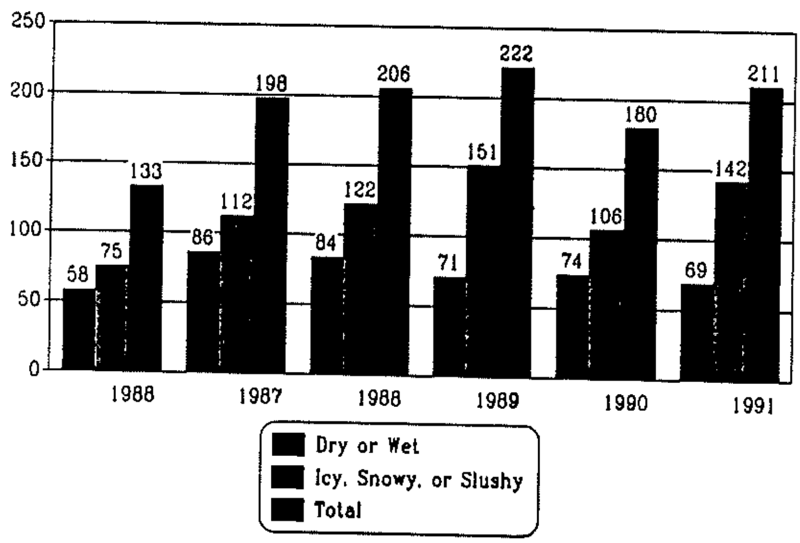


Figure 4.4. Number of Accidents.

SPEED SURVEYS

Spot speed surveys were analyzed to determine if varying degrees of visibility, wind, and pavement conditions were significant factors affecting motorist behavior during periods of poor road and travel conditions. The spot speed survey data were analyzed using Speed Plot, a computer program for calculating 50th and 85th percentile speeds, 10-mile-per-hour pace speeds, percent in pace, speed range, and average speed. The data for passenger cars are presented in Table 4.2, Speed Survey Data—Passenger Cars. The data for trucks are presented in Table 4.3, Speed Survey Data—Trucks.

The road and travel conditions during observation periods were compared to real-time weather data obtained from the WTD remote weather information system (RWIS) located at the Vedauwoo Road Exit. The road and travel conditions were also compared to WTD snow plow operator reports.

There was generally a good relationship between the road and travel conditions during the observation periods and those described by the RWIS. The only measure of visibility was whether or not there was precipitation (either rain or snow). The wind direction and speed in miles per hour were given. The RWIS pavement conditions were described as dry, wet, or snow/ice alert.

There appeared to be a very poor relationship between the road and travel conditions observed during the spot speed surveys and the WTD snow plow operator reports. The snow plow reports did not seem to be as responsive to changes in wind and visibility conditions. The wind probably does not effect the snow plow operators trucks as much as other vehicles due to the combined weight of the trucks and sand in the trucks. The snow plow operators may have rated the visibility conditions differently than the rest of the road users because they have more experience driving in poor visibility conditions and they also have a higher driver eye height. The snow plow operators' reports were also reported for the stretch of

Visibility	Condition Wind	Pavement	Cell Block	Number Observed	Average Speed	85th Percent	Range	Pace	Percent in Pace
Clear	Calm	Dry	1	334	65.3	70	49–83	60–69	70.7
Clear	Calm	Wet	2	272	62.2	67	47–78	57–66	70.2
Clear	Calm	Slushy	3	72	53.2	63	36–72	40–49	40.3
Clear	Calm	Snowpacked	4						
Clear	Calm	Slick Spots	5	91	60.2	65	47–76	56–65	71.4
Clear	Calm	Icy	6						
Clear	Strong Gusty	Dry	7	660	65.7	70	50–90	60–69	72.3
Clear	Strong Gusty	Wet	8						
Clear	Strong Gusty	Slushy	9	62	56.5	64	42–70	52–61	56.5
Clear	Strong Gusty	Snowpacked	10	118	52.7	62	36–70	46–55	49.2
Clear	Strong Gusty	Slick Spots	11	97	61.3	67	45–78	57–66	59.8
Clear	Strong Gusty	Icy	12	91	57.4	64	43–78	53–62	58.2
Limited	Calm	Dry	13	16	61.4	66	54–67	57–66	87.5
Limited	Calm	Wet	14	130	57.9	65	38–75	54–63	57.7
Limited	Calm	Slushy	15	102	53.8	61	31–70	52–61	57.8
Limited	Calm	Snowpacked	16	108	46.8	54	29–63	45–54	46.3
Limited	Calm	Slick Spots	17	29	52.6	57	40–63	48–57	75.9
Limited	Calm	Icy	18	55	54.0	62	31–67	51–60	54.5
Limited	Strong Gusty	Dry	19	63	61.9	68	50–74	58–67	61.9
Limited	Strong Gusty	Wet	20	288	64.6	69	52–85	60–69	72.6
Limited	Strong Gusty	Slushy	21						
Limited	Strong Gusty	Snowpacked	22						
Limited	Strong Gusty	Slick Spots	23	106	52.3	61	34–71	51–60	46.2
Limited	Strong Gusty	Icy	24	75	54.7	62	43–69	49–58	61.3
Very Limited	Calm	Dry	25	105	54.6	60	43–68	51–60	64.8
Very Limited	Calm	Wet	26	110	48.2	55	31–64	43–52	61.8
Very Limited	Calm	Slushy	27	48	44.7	50	31–56	41–50	58.3
Very Limited	Calm	Snowpacked	28	55	43.0	55	25–61	40–49	41.8
Very Limited	Calm	Slick Spots	29	125	50.6	57	34–68	45–54	59.2
Very Limited	Calm	Icy	30	28	50.3	57	40–60	44–53	64.3
Very Limited	Strong Gusty	Dry	31						
Very Limited	Strong Gusty	Wet	32						
Very Limited	Strong Gusty	Slushy	33						
Very Limited	Strong Gusty	Snowpacked	34						
Very Limited	Strong Gusty	Slick Spots	35						
Very Limited	Strong Gusty	Icy	36	85	50.9	60	27–66	52–61	50.6

Table 4.2. Speed Survey Data—Passenger Cars.

	Condition		Cell	Number	Average	85th	Range	Pace	Percent
Visibility	Wind	Pavement	Block	Observed	Speed	Percent			in Pace
Clear	Calm	Dry	1	227	62.6	67	43-75	59-68	71.8
Clear	Calm	Wet	2	230	61.6	67	47-79	57-66	65.7
Clear	Calm	Slushy	3	43	55.5	62	31-70	53-62	53.5
Clear	Calm	Snowpacked	4						
Clear	Calm	Slick Spots	5	56	60.1	66	49-74	52-61	58.9
Clear	Calm	Icy	6						
Clear	Strong Gusty	Dry	7	329	64.3	69	48-78	60-69	71.4
Clear	Strong Gusty	Wet	8						
Clear	Strong Gusty	Slushy	9	36	56.7	65	39-69	52-61	55.6
Clear	Strong Gusty	Snowpacked	10	42	49.9	49	35-66	46-55	57.1
Clear	Strong Gusty	Slick Spots	11	49	58.2	64	43-76	54-63	71.4
Clear	Strong Gusty	Icy	12	50	52.6	62	38-68	45-54	56.0
Limited	Calm	Dry	13	9	60.3	62	53-66	53-62	88.9
Limited	Calm	Wet	14	98	57.4	63	44-71	51-60	64.3
Limited	Calm	Slushy	15	77	54.6	64	31-66	51-60	54.5
Limited	Calm	Snowpacked	16	104	43.9	52	27-61	38-47	49.0
Limited	Calm	Slick Spots	17	23	54.4	62	39-64	54-63	60.9
Limited	Calm	Icy	18	59	52.0	59	31-66	49-58	61.0
Limited	Strong Gusty	Dry	19	51	60.2	65	52-74	56-65	62.7
Limited	Strong Gusty	Wet	20	180	62.6	67	53-80	59-68	71.7
Limited	Strong Gusty	Slushy	21						
Limited	Strong Gusty	Snowpacked	22						
Limited	Strong Gusty	Slick Spots	23	80	55.7	64	35-69	54-63	47.5
Limited	Strong Gusty	Icy	24	47	55.5	63	35-75	48-57	53.2
Very Limited	Calm	Dry	25	76	53.8	59	43-64	51-60	72.4
Very Limited	Calm	Wet	26	125	49.6	55	33-63	45-54	72.0
Very Limited	Calm	Slushy	27	38	45.6	56	31-60	40-49	50.0
Very Limited	Calm	Snowpacked	28	70	37.0	48	16-59	26-35	42.9
Very Limited	Calm	Slick Spots	29	113	51.8	57	38-63	48-57	63.7
Very Limited	Calm	Icy	30	34	50.6	56	37-62	47-56	67.6
Very Limited	Strong Gusty	Dry	31						
Very Limited	Strong Gusty	Wet	32						
Very Limited	Strong Gusty	Slushy	33						
Very Limited	Strong Gusty	Snowpacked	34						
Very Limited	Strong Gusty	Slick Spots	35						
Very Limited	Strong Gusty	Icy	36	64	52.1	60	34-70	47-56	57.8

Table 4.3. Speed Survey Data—Trucks.

Interstate 80 between the Lincoln Monument (MP 323.05) and the County Line (MP 336.61). The road and travel conditions over that stretch often vary substantially.

As noted in Tables 4.2 and 4.3, spot speed surveys were not obtained for ten of the combinations of visibility, wind, and pavement conditions. Also noted in Tables 4.2 and 4.3, the minimum of 50 observations was not obtained for an additional four combinations of conditions for passenger vehicles and nine combinations of conditions for trucks. The data were condensed to improve the number of observations in each cell and remove most of the cells with no observations.

The visibility condition was reduced from three levels (clear, limited, and very limited) to two levels (favorable and poor). That is consistent with previous studies that document that road users' average speed was affected only when visibility is reduced to less than 600 feet. The pavement condition was reduced from six levels (dry, wet, slushy, snowpacked, slick-in-spots, and icy) to three levels (favorable, slick-in-spots, and poor). Dry and wet pavements were combined into favorable and slushy. Snowpacked and icy were combined into poor. Dry and wet were combined into favorable because if the geometric design of highways is based on coefficients of friction for wet pavements, then dry highways would be even more favorable. Slushy, snowpacked, and icy were combined into poor because of their similar effects on road users. The combined spot speed survey data are shown in Table 4.4, Speed Survey Data—Combined.

The data were analyzed using regression analysis procedures included in the SAS statistical computer analysis program. Average speed and percent in the 10-mile-per-hour

Passenger Vehicles

Visibility	Wind	Pavement	Number	Average	85th Percent	Range	10 mph Pace	Percent Pace
Favorable	Calm	Favorable	752	62.8	68	38-83	58-67	68.6
Favorable	Calm	SlickSpots	120	58.4	63	40-76	54-63	72.5
Favorable	Calm	Poor	337	51.5	59	29-72	47-56	49.8
Favorable	Strong Gusty	Favorable	1011	65.2	70	50-90	60-69	71.7
Favorable	Strong Gusty	SlickSpots	203	56.6	64	34-78	54-63	52.7
Favorable	Strong Gusty	Poor	346	55.1	63	36-78	50-59	55.5
Poor	Calm	Favorable	215	51.3	57	31-68	47-56	63.3
Poor	Calm	SlickSpots	125	50.6	57	34-68	45-54	59.2
Poor	Calm	Poor	131	45.2	54	25-61	41-50	52.7
Poor	Strong Gusty	Favorable						
Poor	Strong Gusty	SlickSpots						
Poor	Strong Gusty	Poor	85	50.9	60	27-66	52-61	50.6

Trucks

Visibility	Wind	Pavement	Number	Average	85th Percent	Range	10 mph Pace	Percent Pace
Favorable	Calm	Favorable	564	61.3	66	43-79	57-66	68.3
Favorable	Calm	SlickSpots	79	58.4	65	39-74	53-62	59.5
Favorable	Calm	Poor	283	50.3	58	27-70	46-55	53.7
Favorable	Strong Gusty	Favorable	560	63.4	68	48-80	59-68	70.7
Favorable	Strong Gusty	SlickSpots	129	56.6	64	35-76	54-63	56.6
Favorable	Strong Gusty	Poor	175	53.6	62	35-75	48-57	55.4
Poor	Calm	Favorable	201	51.2	57	33-64	47-56	72.2
Poor	Calm	SlickSpots	113	51.8	57	38-63	48-57	63.7
Poor	Calm	Poor	142	42.6	52	31-62	34-43	50.7
Poor	Strong Gusty	Favorable						
Poor	Strong Gusty	SlickSpots						
Poor	Strong Gusty	Poor	64	52.1	60	34-70	47-56	57.8

Table 4.4. Speed Survey Data—Combined.

pace were the dependent variables used to evaluate the effect of poor road and travel conditions on road users.

Average Speed

The dependent variable average speed was modelled against the predictors visibility, wind, pavement, vehicle type, visibility*wind, visibility*pavement, visibility*vehicle type, wind*pavement, wind*vehicle type, pavement*vehicle type, and pavement*pavement. The predictor, coefficient, and t-statistic are shown in Table 4.5, Average Speed—Full Model.

As shown in Table 4.5, only visibility would be considered a significant predictor of average speed. However, this analysis calculates the coefficients with all other predictors in the model. A forward stepwise regression analysis was performed to determine the best predictors by finding the best predictor and then incrementally adding the next-best predictors to improve the model. The forward stepwise model building process chose visibility, pavement, and visibility*wind as the best predictors of average speed. A backward regression analysis was performed to determine the best predictors by including all predictors in the model and then incrementally removing poor predictors from the model. The best model found by using the backward elimination process included also included visibility, visibility*wind, and pavement. A maximum R^2 stepwise model building procedure was also employed. The maximum R^2 method finds the best one-predictor model, the best two-predictor model and so forth. The best model chosen using the maximum R^2 method included visibility, visibility*wind, and pavement.

Table 4.5. Average Speed—Full Model.

Analysis of Variance		
Source	Degrees of Freedom	F-Value
Model	11	13.142
Error	8	
Total	19	

Predictor Estimates

Predictor	Degrees of Freedom	Coefficient (B)	T-statistic (Ho: B=0)	Ho:
Intercept	1	64.0201	20.771	Reject
Visibility (V)	1	-11.8564	-3.326	Reject
Wind (W)	1	-0.0231	-0.006	Accept
Pavement (P)	1	-3.4724	-1.192	Accept
Vehicle Type (T)	1	-1.0949	-0.597	Accept
V*W	1	4.8056	1.725	Accept
V*P	1	1.9000	1.286	Accept
V*T	1	1.0821	0.539	Accept
W*P	1	0.6000	0.406	Accept
W*T	1	0.4821	0.240	Accept
P*T	1	-0.1462	-0.126	Accept
P*P	1	-0.9417	-0.901	Accept

Note: F(0.05, 11, 8) = 3.315, T(0.05, 8) = 1.860.

All three stepwise regression models found the model including visibility, visibility*wind, and pavement as the best predictors of average speed. The regression analysis including only the predictors for the best model is listed in Table 4.6, Average Speed—Best Model.

The resulting best model for predicting average speed was

$$\textit{Average Speed} = 62.5 - 9.0V + 7.5VW - 4.7P$$

Where: V-Visibility: 0=Favorable
1=Poor
W-Wind: 0=Calm
1=Strong and Gusty
P-Pavement: 0=Favorable
1=Slick in Spots
2=Poor

The resulting coefficient of determination for the model was R^2=0.92, showing a good relationship between the predictors and average speed. The visibility and pavement conditions were the most important factors affecting average speed. The interaction between visibility and wind was also a significant factor. It should also be noted that vehicle type was not a significant factor.

Average speed data were collected for three of the combinations of conditions during darkness. The comparisons in average speeds for light and dark conditions are shown in Table 4.7, Light Condition Comparisons—Average Speed.

The darkness condition only affected the average speed of road users when road conditions were poor. Night time travel speeds were reduced by approximately eight miles per hour when conditions were very poor.

Table 4.6. Average Speed—Best Model.

Analysis of Variance		
Source	Degrees of Freedom	F-Value
Model	3	59.994
Error	16	
Total	19	

Predictor Estimates				
Predictor	Degrees of Freedom	Coefficient (B)	T-statistic (Ho: B=0)	Ho:
Intercept	1	62.5083	83.042	Reject
Visibility (V)	1	-8.9833	-9.744	Reject
Pavement (P)	1	-4.7417	-8.909	Reject
V*W	1	7.4583	4.671	Reject

Note: F(0.05, 11, 8) = 3.290, T(0.05, 8) = 1.746.

Percent in Pace

The dependent variable, percent in pace, was modelled against the predictors visibility, wind, pavement, vehicle type, visibility*wind, visibility*pavement, visibility*vehicle type, wind*pavement, wind*vehicle type, pavement*vehicle type, and pavement*pavement. The analysis of variance, predictor, coefficient, and t-statistic are shown in Table 4.8, Percent in Pace—Full Model.

As shown in Table 4.8, none of the predictors relate very well to the percent in pace. Again, this analysis calculates the coefficients with all other predictors in the model. The forward stepwise, backward elimination, and maximum R^2 model building processes chose only pavement as a significant predictor of percent in pace. The regression analysis including only pavement is listed in Table 4.9, Percent in Pace—Best Model.

Table 4.7. Light Condition Comparisons—Average Speed.

Road Conditions	Light Average Speed		Dark Average Speed		Significant Difference	
	PV	T	PV	T	PV	T
Favorable Visibility Calm Winds Favorable Pavement	62.8	61.3	62.1	62.2	No	No
Favorable Visibility Strong, Gusty Winds Slck/Spts Pavement	56.6	56.6	51.0	48.9	Yes	Yes
Poor Visibility Calm Winds Poor Pavement	45.2	42.6	38.9	37.7	Yes	Yes

Note: PV = Passenger Vehicles, T = Trucks

The best model for predicting percent in pace was

$$\textit{Average Speed} = 68.9 - 7.9P$$

Where: P-Pavement: 0=Favorable
1=Slick in Spots
2=Poor

Table 4.8. Percent in Pace—Full Model.

Analysis of Variance

Source	Degrees of Freedom	F-Value
Model	11	2.625
Error	8	
Total	19	

Predictor Estimates

Predictor	Degrees of Freedom	Coefficient (B)	T-statistic (Ho: B=0)	Ho:
Intercept	1	73.8872	8.758	Reject
Visibility (V)	1	-12.6301	-1.294	Accept
Wind (W)	1	-8.3468	-0.855	Accept
Pavement (P)	1	-7.6346	-0.958	Accept
Vehicle Type (T)	1	-2.2359	-0.446	Accept
V*W	1	2.9667	0.389	Accept
V*P	1	0.3250	0.080	Accept
V*T	1	7.0256	1.278	Accept
W*P	1	0.4750	0.117	Accept
W*T	1	4.1590	0.757	Accept
P*T	1	-0.9436	-0.297	Accept
P*P	1	0.3500	0.122	Accept

Note: F(0.05, 11, 8) = 3.315, T(0.05, 8) = 1.860.

Table 4.9. Percent in Pace—Best Model.

Analysis of Variance		
Source	Degrees of Freedom	F-Value
Model	1	45.205
Error	18	
Total	19	

Predictor Estimates				
Predictor	Degrees of Freedom	Coefficient (B)	T-statistic (Ho: B=0)	Ho:
Intercept	1	68.9580	42.538	Reject
Pavement (P)	1	-7.9072	-6.723	Reject

Note: F(0.05, 1, 18) = 4.410, T(0.05, 18) = 1.734.

The resulting coefficient of determination for the model was R^2=0.72, for the relationship between pavement and percent in pace. The comparisons between light and dark conditions are shown in Table 4.10, Light Condition Comparisons—Percent in Pace. The data seem to indicate that the percent in pace increases during dark conditions. This tends to indicate that road users travel at more consistent speeds during darkness.

REMOTE WEATHER INFORMATION SYSTEM—ROAD USER SURVEYS

An analysis was performed to determine the relationships between the road and travel conditions as described by data obtained from the remote weather information system (RWIS), and the road and travel conditions as described by the road users in the road user surveys. The data from the RWIS, located at the Vedauwoo Road Exit, describes real-time conditions at that particular location in Section 2. The road user surveys described conditions for the entire 41 mile distance between Laramie and Cheyenne.

Table 4.10. Light Condition Comparisons—Percent in Pace.

Road Conditions	Light Average Speed		Dark Average Speed		Significant Difference	
	PV	T	PV	T	PV	T
Favorable Visibility Calm Winds Favorable Pavement	68.6	68.3	70.6	74.2	No	No
Favorable Visibility Strong, Gusty Winds Slck/Spts Pavement	52.7	56.6	66.7	88.9	Yes	Yes
Poor Visibility Calm Winds Poor Pavement	52.7	50.7	59.6	59.0	Yes	Yes

Note: PV = Passenger Vehicles, T = Trucks

The relationships between the RWIS and the road user surveys were analyzed by segmenting road and travel conditions into visibility, wind, and pavement conditions. The RWIS provides data that describe weather conditions in terms of presence of precipitation, wind speed and direction, and pavement condition—dry, wet, chemical wet, or snow/ice alert. The road users described conditions in terms of visibility (clear, limited, or very limited), wind (calm or strong and gusty), and pavement conditions (dry, wet, slushy, snowpacked, slick-in-spots, or icy).

The RWIS data were updated as a significant change occurred in a measured parameter. The date and time of the change was recorded and all of the measured parameters were updated by the RWIS. The RWIS data and the road user surveys were correlated by date and time of travel.

The first RWIS-road user comparison was performed for the visibility condition. The cross table between precipitation (RWIS) and visibility condition (road user survey) showing the number of observations in each condition is listed in Table 4.11, Visibility—RWIS vs. Road User Surveys.

The road users reported the visibility condition as clear 520 times (70.6 percent), as limited 176 times (23.9 percent), and as very limited 41 times (5.6 percent) during the 737 trips made by road user respondents when no precipitation was present. The road users reported the visibility condition as clear 303 times (35.4 percent), as limited 368 times (43.0 percent), and as very limited 185 times (21.6 percent) during the 856 trips made when precipitation was present. When precipitation existed no definitive determination was made concerning the visibility conditions, since the RWIS does not record this information.

Table 4.11. Visibility—RWIS vs. Road User Surveys.

RWIS	Road User Surveys			
Precipitation	Clear	Limited	Very Limited	TOTAL
No	520	176	41	737
Yes	303	368	185	856
TOTAL	823	544	226	1,593

The second RWIS-road user comparison was performed for the wind condition. Depicted in Figure 4.5, Wind—RWIS vs. Road User Surveys, are the percentage of times that the wind condition was classified as strong and gusty by the road users, for each five mph grouping of wind speed (as measured by the RWIS).

As reported in Figure 4.5, the road users rated the wind condition as strong and gusty approximately 70 percent of the time for wind speeds of 16 to 20 miles per hour. This 16 to 20 mph wind grouping was used to determine the criteria for strong and gusty winds as rated by the road users. The WTD currently uses a wind speed of 25 miles per hour for poor road conditions and 35 miles per hour for dry road conditions as criteria for displaying high wind warnings on variable message signs.

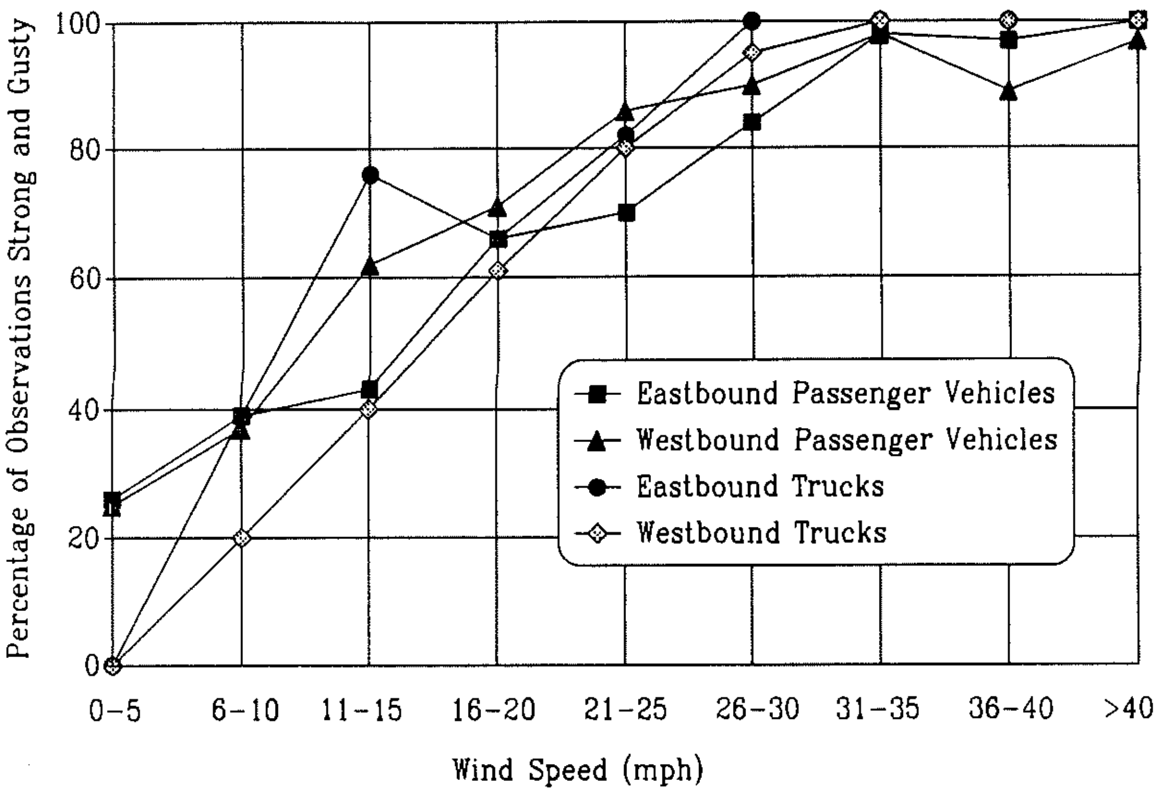


Figure 4.5. Wind—RWIS vs. Road Users Surveys.

The last RWIS-road user comparison concerns the pavement condition. The resulting cross table between pavement status (RWIS) and pavement condition (road user survey) are listed in Table 4.12, Pavement Condition—RWIS vs. Road User Surveys. The following observations are made concerning the pavement condition relationships listed in Table 4.12:

Road users reported the pavement conditions as dry 411 times (52.8 percent), wet 62 times (8.0 percent), slushy, snowpacked, or icy 70 times (9.0 percent), and slick-in-spots 236 times (30.3 percent) during the 779 trips made when the RWIS pavement status was dry.

Table 4.12. Pavement Condition—RWIS vs. Road User Surveys.

RWIS	Road User Surveys						
Status	Dry	Wet	Slushy	Snow-packed	Slick in Spots	Icy	TOTAL
Dry	411	62	11	19	236	40	779
Wet	5	12	15	4	34	9	79
Chemical Wet	1	4	3	4	66	58	136
Snow / Ice Alert	39	14	7	44	285	165	554
TOTAL	456	92	36	71	621	272	1,548

Road users reported the pavement conditions as slick-in-spots or icy 124 times (91.2 percent) during the 136 trips made when the RWIS pavement status was chemical wet.

Road users reported the pavement conditions as dry 39 times (7.0 percent), wet 14 times (2.5 percent), slushy 7 times (1.3 percent), snowpacked 71 times (12.8 percent), slick-in-spots 285 times (51.4 percent), and icy 165 times (29.8 percent) during the 554 trips made when the RWIS pavement status was snow/ice alert.

These observations illustrate that the RWIS pavement status does not relate well to the pavement conditions described by the road users.

REMOTE WEATHER INFORMATION SYSTEM — SNOW PLOW OPERATOR REPORTS

An analysis was performed to determine the relationships between the road and travel conditions as described by data obtained from the remote weather information system (RWIS) and the road and travel conditions as described by the WTD snow plow operators reports. The data from the RWIS, located at the Vedauwoo Road Exit, describes real-time conditions at that particular location in Section 2. The snow plow reports describe conditions over the entire 12 mile distance in Section 2 between Lincoln Monument and the Buford Exit.

The relationships between the RWIS and the snow plow reports in Section 2 were analyzed by dividing the road and travel conditions into visibility, wind, and pavement categories. The RWIS data described road and travel conditions in terms of whether or not there was precipitation present, wind speed and direction, and pavement condition—dry, wet, chemical wet, or snow/ice alert. The snow plow operators described the road and travel conditions in terms of visibility (clear, limited, or very limited), wind (calm or strong and gusty), and pavement conditions (dry, wet, slushy, snowpacked, slick-in-spots, or icy).

The RWIS data were updated when a significant change occurred in a measured parameter. The date and time of the change was logged as all of the measured parameters were updated by the RWIS. The snow plow operator reports were correlated to the RWIS data by matching the nearest RWIS entry to the time of the snow plow operator report.

The first RWIS-road user comparison was the visibility condition. The resulting cross table between precipitation (RWIS) and visibility condition (road user survey) showin the number of observations in each condition is listed in Table 4.13, Visibility—RWIS vs. Snow Plow Operator Reports.

Table 4.13. Visibility—RWIS vs. Snow Plow Operator Reports.

RWIS	Snow Plow Operator Reports			
Precipitation	Clear	Limited	Very Limited	TOTAL
No	200	26	5	231
Yes	238	53	26	317
TOTAL	438	79	31	548

As reported in Table 4.13, the snow plow operators reported the visibility condition as clear 200 times (86.6 percent), as limited 26 times (11.3 percent), and as very limited 5 times (2.2 percent) when no precipitation was present. The snow plow operators reported the visibility condition as clear 238 times (75.1 percent), as limited 53 times (16.7 percent), and as very limited 31 times (9.8 percent) when precipitation was present. It was noted that, when there was no precipitation, there was not likely to be a visibility problem unless there was fog or blowing snow. Although even when the RWIS indicated that precipitation existed, no positive determination could be made about the visibility conditions.

The second RWIS-road user comparison was made for the wind condition. Depicted in Figure 4.6, Wind—RWIS vs. Snow Plow Operator Reports, are the percentage of times that the wind condition was classified as strong and gusty for each five-mile-per-hour grouping of wind speed as measured by the RWIS.

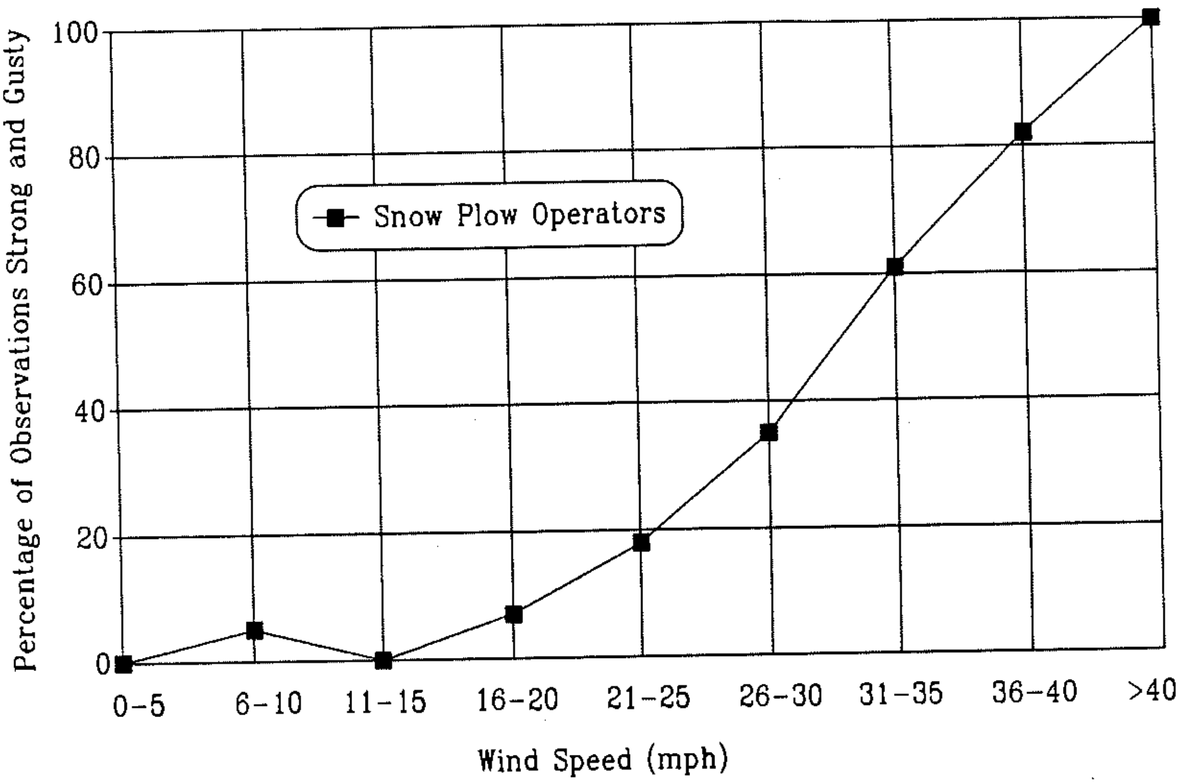


Figure 4.6. Wind—RWIS vs. Snow Plow Operator Reports.

As the data in Figure 4.6 indicate, the snow plow operators reported the wind condition as strong and gusty approximately 65 percent of the time for wind speeds of 31 to 35 miles per hour. The snow plow operators reported wind conditions consistently with the current WTD criteria for high wind warnings.

The last RWIS—snow plow operator comparison was made for the pavement condition. The resulting cross table between pavement status (RWIS) and pavement condition (snow plow operator reports) is listed in Table 4.14, Pavement Condition—RWIS vs. Snow Plow Operator Reports.

Table 4.14. Pavement Condition—RWIS vs. Snow Plow Operator Reports.

RWIS	Road User Surveys						
Status	Dry	Wet	Slushy	Snow-packed	Slick in Spots	Icy	TOTAL
Dry	86	21	0	5	134	4	250
Wet	1	7	0	5	39	2	54
Chemical Wet	0	0	0	6	46	0	52
Snow / Ice Alert	8	1	0	8	147	28	192
TOTAL	95	29	0	24	366	34	548

The following observations are made concerning the pavement condition relationships listed in Table 4.14:

Snow plow operators reported the pavement conditions as dry 86 times (34.4 percent), as wet 21 times (8.4 percent), as snowpacked or as icy

9 times (3.6 percent) times, and slick-in-spots 134 times (53.6 percent) when the RWIS pavement status was dry.

Snow plow operators reported the pavement conditions as slick-in-spots 39 times (75.0 percent) of the total 54 RWIS entries that the pavement status was wet.

Snow plow operators reported the pavement conditions as snowpacked or slick-in-spots all 52 times (100.0 percent) the log entries were made when the RWIS pavement status was chemical wet.

Snow plow operators reported the pavement conditions as dry eight times (4.2 percent), as wet one time (0.5 percent), as snowpacked eight times (4.2 percent), as slick-in-spots 147 times (76.6 percent), and as icy 28 times (14.6 percent) when the RWIS pavement status was snow/ice alert.

The data and observations illustrate that the RWIS pavement status does not relate well to the pavement conditions described by the snow plow operators.

ROAD USER SURVEYS—SNOW PLOW OPERATOR REPORTS

An analysis was performed to determine the relationships between the road and travel conditions as described in the road user surveys and road and travel conditions as described by the WTD snow plow operator reports. The road user survey data describes road and travel conditions for a trip made between Laramie and Cheyenne. The snow plow reports describe road and travel conditions in Section 2, which is a 12 mile distance between the Lincoln Monument and the Buford Exit.

The departure and arrival dates and times of the road user surveys were used to correlate to the time of the snow plow operator reports. The road user surveys were correlated to the snow plow operator reports by matching the nearest snow plow operator report entry to the estimated time the road user was traveling through Section 2.

The first road user survey—snow plow operator report comparison was made for the visibility condition. The resulting cross table between road users and snow plow operators reports showing the number of observations in each condition is listed in Table 4.15, Visibility—Road User Surveys vs. Snow Plow Operator Reports.

Table 4.15. Visibility—Road User Surveys vs. Snow Plow Operator Reports.

Road Users	Snow Plow Operator Reports			
Visibility	Clear	Limited	Very Limited	TOTAL
Clear	568	75	6	649
Limited	342	100	15	457
Very Limited	159	37	17	213
TOTAL	1,069	212	38	1,319

The road users and snow plow operators reported the visibility condition the same 703 times (53.3 percent) of the total 1,319 observations. The snow plow operators reported the visibility condition worse than the road users reported the visibility condition 96 times or 7.3 percent. The road user reported the visibility condition worse that the snow plow operators reported the visibility condition 538 times, or 40.8 percent. The road users tended to report the visibility conditions as worse than the snow plow operators.

The second road user—snow plow operator comparison was for the wind condition. The cross table results are listed in Table 4.16, Wind—Road User Surveys vs. Snow Plow Operator Reports.

The road users and the snow plow operators reported the wind condition the same 595 times (45.3 percent). The road users reported the wind condition as calm when the snow plow operators reported the wind condition as strong and gusty only 13 times (1.0 percent). The road users reported the wind condition as strong and gusty when the snow plow operators reported the wind condition as calm 706 times (53.7 percent). The road users reported strong and gusty winds more often than snow plow operators.

Table 4.16. Wind—Road User Surveys vs. Snow Plow Operator Reports.

Road Users	Snow Plow Operators		
Wind	Calm	Strong and Gusty	TOTAL
Calm	378	13	391
Strong and Gusty	706	217	923
TOTAL	1,084	230	1,314

The last road user—snow plow operator comparison was made for the pavement condition. The resulting cross table between pavement condition (road user) and pavement condition (snow plow operator) is listed in Table 4.17, Pavement Condition—Road User Surveys vs. Snow Plow Operator Reports.

The following observations are made concerning the pavement condition relationships listed in Table 4.17:

The road users reported the pavement conditions the same 692 times (52.5 percent), worse 385 times (29.2 percent), and better 242 times (18.3 percent) than the snow plow operators.

The snow plow operators reported the pavement conditions as slick-in-spots 896 times (67.9 percent) of the 1,319 observations.

Table 4.17. Pavement Condition—Road User Surveys vs. Snow Plow Operator Reports.

Road User	Snow Plow Operator Reports						
Pavement Condition	Dry	Wet	Slushy	Snow-packed	Slick in Spots	Icy	TOTAL
Dry	185	6	0	2	82	2	277
Wet	13	13	0	4	39	5	74
Slushy	1	4	0	2	26	0	33
Snow-packed	4	1	0	7	54	3	69
Slick in Spots	31	24	0	28	474	43	600
Icy	3	4	0	25	221	13	266
TOTAL	237	52	0	68	896	66	1,319

The snow plow operators generally tended to report the pavement conditions as slick-in-spots. Road users tended to agree, however many reported icy conditions.

SNOW PLOW OPERATOR REPORTS

The snow plow reports for each section were compared to determine consistencies within the snow plow reporting system. First, the snow plow reports were compared for Section 1 (Laramie to Lincoln Monument) and Section 2 (Lincoln Monument to the Buford Exit). The visibility conditions were reported as the same 96.1 percent of the time. The visibility conditions were worse in Section 2 than in Section 1, 3.1 percent of the time. The visibility conditions were worse in Section 1 than in Section 2 only three times that snow plow operator reports were recorded. The wind condition was reported as the same 98.7 percent of the time. The pavement condition was reported as the same 95.5 percent of the time. The pavement conditions were worse in Section 2 than in Section 1, 2.0 percent of the time.

Secondly, the snow plow operator reports were compared for Section 3 (Buford Exit to Harriman Exit) and Section 4 (Harriman Exit to Cheyenne). The visibility condition was reported the same 96.1 percent of the time. The visibility condition was reported worse in Section 3 than Section 4, 3.3 percent of the time. The wind condition was reported the same 99.4 percent of the time. The pavement condition was reported the same 88.0 percent of the time. The pavement condition was reported worse in Section 3 than 4, 11.3 percent of the time.

Lastly, the snow plow operator reports were compared for Section 2 (Lincoln Monument to Buford Exit) and Section 3 (Buford Exit to Harriman Exit). The visibility conditions were reported the same 86.1 percent of the time. The visibility conditions were reported worse in Section 2 than in Section 3, 10.2 percent of the time. The wind conditions were reported the same 91.0 percent of the time. The pavement conditions were reported the same 55.1 percent of the time. The pavement conditions were reported worse in Section 2 than Section 3, 38.2 percent of the time.

As noted above, the snow plow operator reports seemed to be split into two groups—Sections 1 and 2 and Sections 3 and 4. The visibility, wind, and pavement conditions were reported similarly in Sections 1 and 2. Also the visibility, wind, and pavement conditions were almost always the same in Sections 3 and 4. The snow plow reports also indicate that poor road and travel conditions existed in Section 1, 3, or 4 only when there were poor road and travel conditions in Section 2. It should be noted that the snow plow operators maintaining Sections 1 and 2 were based in Laramie and the snow plow operators maintaining Sections 3 and 4 were based in Cheyenne.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The summaries of findings, conclusions, and recommendations of the study are presented in the following sections.

SUMMARY

The accident rates for road users during poor road conditions were much higher than accident rates for road users during favorable road conditions for all combinations of vehicle type and driver proximity.

The yearly number of accidents when the road conditions were poor was about 60 percent higher than the yearly number of accidents when road conditions were favorable. The accidents that occurred during poor road conditions happened in a time span that amounted to approximately ten percent of the total time during the year.

The average speed of road users was affected the most by poor pavement conditions. Poor visibility and strong and gusty winds were also significant factors affecting the average speed of motorists. The visibility*wind interaction was also a significant factor. Darkness affected the road users average speed only if poor road and travel conditions existed. The percent of road users traveling in the 10-mile-per-hour pace was reduced during times of adverse pavement conditions.

There was very little correlation between the visibility reported by the road users and precipitation measured by the RWIS. The majority of road users rated the winds as strong and gusty when the RWIS measured wind speeds of 15 to 20 miles per hour.

Pavement conditions reported by the road users did not correlate well to the pavement status provided in the RWIS data.

As with the road user reports, the visibility conditions reported by the snow plow operator reports did not correlate very well with the presence of precipitation as measured by the RWIS. Strong and gusty winds relate to the current criteria used by the WTD. Pavement conditions reported by the snow plow operators did not correlate well with the pavement status provided by the RWIS.

Road users generally tended to report the visibility conditions worse than the snow plow operators during inclement weather conditions. Road users also reported strong and gusty winds at lower wind speeds as measured by the RWIS than did the snow plow operators. Road users tended to rate the pavement conditions worse than the snow plow operators. The snow plow operators generally tended to describe adverse pavement conditions as slick-in-spots.

The road and travel conditions as described by the snow plow operators are comparable in Sections 1 and 2 (Laramie to Buford) and in Sections 3 and 4 (Buford to Cheyenne). The conditions were almost always worse in Sections 1 and 2 than in Sections 3 and 4.

CONCLUSIONS

Safety improvements are needed to reduce the number of winter time accidents. Possible solutions for addressing the winter time accident problem are education of winter time driving strategies and improved communication of current road conditions.

Poor visibility and pavement conditions have the most effect on the average speeds of road users traveling during inclement road and travel conditions. Road users adjusted their travel speeds depending on their perception of the severity of the road and travel conditions. Road users need to be educated on safe winter weather driving strategies. Road users need to be educated as to what constitutes severe and poor conditions and also what would be considered safe driving habits during those conditions. Current road and travel information should be conveyed to the road users so that they may make informed decisions concerning making a trip during potentially hazardous degrees of adverse road and travel conditions.

There was very little correlation between the conditions described by the remote weather information system, road user surveys, and snow plow operator reports. The conditions described by the present RWIS did not relate to the overall conditions of the roadway as described by either the road users or the snow plow operators. Therefore, the existing RWIS should not be used solely to determine poor road and travel conditions.

The correlation between the visibility and wind conditions described by the road users and the visibility and wind conditions described by the snow plow operators was poor. This was perhaps due to the road users having relatively less experience driving in poor conditions and differences in the vehicle types. Seasoned snow plow operators have seen the worst possible conditions many times; visibility and wind conditions that are very poor to road users may not seem that bad to the snow plow operators.

The snow plow operators were also operating vehicles that, on the whole, are larger and heavier than the vehicles being operated by the road users. Road users are operating passenger vehicles that are much lighter than the snow plows either unloaded or loaded with sand and therefore are more affected by strong and gusty winds. Poor visibility caused by blowing snow affects the road users operating passenger vehicles more than snow plow operators because of a lower driver eye height as compared to the snow plow operator eye height. Road users operating trucks, such as moving vans, are larger than snow plows and therefore are also more affected by strong and gusty winds. Road users also tended to rate the pavement conditions worse than the snow plow operators, which was most likely due to the difference in driving experience of the road users and snow plow operators in poor road and travel conditions.

The RWIS was located in a very advantageous location between Laramie and Cheyenne. Poor road and travel conditions were almost always reported in that section if they existed between Laramie and Cheyenne. One reason that conditions were reported similarly in Sections 1 and 2 and in Sections 3 and 4 may have been because the snow plow operators maintaining Sections 1 and 2 were based in Laramie and the snow plows maintaining Sections 3 and 4 were based in Cheyenne.

RECOMMENDATIONS

A project to develop information on safe winter driving strategies should be performed. Most importantly, the information should address safe advisory speeds to be recommended during specific poor road and travel conditions. Information concerning necessary travel, safe following distances, emergency or evasive maneuvers, and emergency preparedness should be included. Road users should be advised of the risk of traveling during poor road and travel conditions to determine if their trip purpose justifies the risk. Safe following distances for specific road and travel conditions should be recommended based on available stopping sight distance and pavement condition. Emergency or evasive maneuvers should be recommended for the safest places to stop when conditions deteriorate to a level that road users should stop and wait for conditions to improve. Emergency preparedness information should be assembled so that stranded road users know what to do and have the proper supplies in case of emergency. The information concerning these safe driving strategies should be conveyed to the traveling public in drivers' license exam procedures, port-of-entry handouts, and local media to maximize exposure.

Permanent traffic speed monitoring stations should be installed with additional improved RWIS stations including particle counters for measuring visibility. Reductions in the average speed or percent in pace of road users should be used in conjunction with the expanded RWIS data to determine the road and travel conditions being encountered by the road users. Speed data collected in this manner during different road and travel conditions described by RWIS could be used to determine the advisory speeds as recommended earlier.

The current remote weather information system does not provide adequate information to accurately determine the road and travel conditions for Interstate 80 between Laramie and Cheyenne. If use of the RWIS to determine road and travel conditions is to be continued, the RWIS should be upgraded to include more weather sensor locations and to include visibility measurement devices.

The additional weather sensor stations would improve the system by sensing poor road and travel conditions at more than one location. This would improve the reliability by indicating poor road and travel conditions that would be applicable to a wider segment of the roadway between Laramie and Cheyenne.

The wind speed criteria currently used by the WTD for high wind warnings should be lowered to levels consistent with the road user ratings. The RWIS pavement status could be used to supplement other sources of information but should not be used alone due to the poor correlation of the pavement status at Vedauwoo and actual conditions over the 41 mile distance between Laramie and Cheyenne. More RWIS sensors would provide the pavement status at more locations, improving the reliability of the system.

Should more RWIS sensor locations not be installed, removal of the RWIS should be considered, since the existing RWIS does not reliably describe road and travel conditions over the 41 mile distance between Laramie and Cheyenne.

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