FINAL REPORT

FHWA-WY-10/04F

State of Wyoming
Department of Transportation

U.S. Department of Transportation
Federal Highway Administration

VARIABLE SPEED LIMIT SYSTEM FOR ELK MOUNTAIN CORRIDOR

By:

Department of Civil and Architectural Engineering
1000 E. University Way
Laramie, Wyoming 82071

October 2010

Notice

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Technical Report Documentation Page

Report No.	Government Accession No.	Recipients Catalog No.
FHWA-WY-10/04F		

Title and Subtitle VARIABLE SPEED LIMITS SYSTEM FOR ELK MOUNTAIN CORRIDOR	Report Date October 2010 Performing Organization Code
Author(s) Jenna Buddemeyer, Rhonda Young, Vijay Sabawat, and Emily Layton	Performing Organization Report No.
Performing Organization Name and Address Department of Civil and Architectural Engineering University of Wyoming 1000 E. University Way Dept 3295 Laramie, WY 82071	Work Unit No. RS05207 Contact or Grant No.
Sponsoring Agency Name and Address Wyoming Department of Transportation 5300 Bishop Blvd. Cheyenne, WY 82009-3340 WYDOT Research Center (307) 777-4182	Type of Report and Period Covered August 2007 – June 2010 Sponsoring Agency Code

Supplementary Notes

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Abstract

Determining an appropriate speed for the current conditions can be difficult for the driver. Equally difficult is for law enforcement agencies to enforce and cite someone going too fast for conditions. In many cases, drivers are cited for going too fast for conditions only after the accident has occurred. Variable speed limits (VSL) are one type of intelligent transportation system (ITS) that has shown promise for improving safety on roadways subject to adverse conditions. The purpose of this research was to lay the foundation for the new I-80 VSL system in southeastern Wyoming. During this phase of the research, surveys were sent out to all DOTs to see what VSLs have been implemented in the U.S. Driver speed behaviors during both "ideal" and "non-ideal" conditions were found and baseline speeds determined. Weather and speed data were analyzed to determine key variables and threshold values. To check how cars and trucks are reacting to the VSL system individual speed analysis was done. A draft version of control strategy was designed and a simulation was run to check for level of speed compliance. The final task was to determine how drivers are reacting to the new VSL system.

Key Words Variable Speed Limit System, Speed Limits, Speed Compliance, Wyoming, WYDOT		Distribution Statement Unlimited	
Security Classif. (of this report) Unclassified	Security Classif. (of this page) Unclassified	No. of Pages 428	Price

Form DOT F 1700.7 (8-72) Reproduction of form and completed page is authorized.

SI* (Modern Metric) Conversion Factors

Approximate Conversions from SI Units

Symbol	When You Know	Multiply By	To Find	Symbol
Length				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
Area				
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
Volume				
ml	milliliters	0.034	fluid ounces	fl oz
l	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
Mass				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg	megagrams	1.103	short tons (2000 lbs)	T
Temperature (exact)				
°C	Centigrade temperature	1.8 C + 32	Fahrenheit temperature	°F
Illumination				
lx	lux	0.0929	foot-candles	fc
cd/m^2	$candela/m^2$	0.2919	foot-Lamberts	fl
Force and Pressure or Stress				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	pound-force per square inch	psi

Approximate Conversions to SI Units

Symbol	When You Know	Multiply By	To Find	Symbol
Length				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
Area				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
Volume				
fl oz	fluid ounces	29.57	milliliters	ml
gal	gallons	3.785	liters	l
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
Mass				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lbs)	0.907	megagrams	Mg
Temperature (exact)				
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celsius temperature	°C
Illumination				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	$candela/m^2$	cd/m^2
Force and Pressure or Stress				
lbf	pound-force	4.45	newtons	N
psi	pound-force per square inch	6.89	kilopascals	kPa

Executive Summary

The main goals of this research project are to implement a Variable Speed Limit (VSL) system to improve safety and reduce closure frequency and durations on the Elk Mountain corridor. A draft decision support system has been created to effectively and consistently implement the Elk Mountain VSL system. The decision support system was created to reduce the speed variability in the corridor during adverse weather conditions, which should result in fewer crashes and shorter road closures over the long term.

The Elk Mountain corridor is located in southeastern Wyoming on Interstate 80 between Laramie and Rawlins. The corridor carries approximately 11,000 vehicles per day. On average, approximately half or more of those vehicles are trucks carrying freight. Prior to this project, the ITS components that were available for drivers on I-80 between Laramie and Rawlins were a road weather information system (RWIS) and dynamic message (DMS) signs that are located at either end of the corridor (mileposts 234.6 and 311.1). WYDOT implemented a VSL system along the Elk Mountain corridor during February 2009. The VSL system included 20 variable speed limit signs at ten locations (5 in the eastbound and 5 in the westbound directions) and 10 speed sensors. The VSL system was expanded in the 2009-2010 winter season to include 8 additional variable speed limit signs in four new locations (2 in the eastbound and 2 in the westbound directions).

One of the main data sources were the ten speed sensors located along the corridor. These speed sensors were used to obtain observed speeds from cars and trucks. The ten speed sensors encountered problems with communications and data storage during the entire study period and the two software programs used by WYDOT at

different times during the project to process the data provided different variables. Another major data source was the information collected from the Road Weather Information Systems (RWIS) station located approximately in the middle of the corridor. The RWIS data indicated the weather conditions on the corridor. The final data source was the VSL database, which provided the VSL system use information. The frequency and duration of adjusted speed limits could be analyzed from the VSL data.

The following sections summarize and highlight the important aspects of the research tasks described in detail in previous chapters. The future research tasks for Phase II of the project will also be discussed.

DOT Surveys

State DOT surveys were completed to gain information about operating VSL systems in the U.S. From the survey that was sent to each state DOT, it was concluded that each system operates differently. Each state DOT operates their system in the way that benefits their state. The urban systems are monitoring incidents and speeds, whereas the majority of the rural systems are monitoring visibility, weather, and pavement conditions.

Each state has a different method of setting thresholds, which has resulted in a difference in the types of thresholds that have been established. Nine states are using LED signs, one is using VMS, and one is using Static Panel signs. Virginia is the only system that is automated. The other ten states require dispatch approval/verification before changing the speeds. Formal evaluations have not been completed on some of the corridors, but overall each DOT believes that the system is working on their corridors.

Crash Analysis

The overall goal of this project is to improve safety along the corridor as measured by the number of crashes that occur. Crash records for the first full year of VSL system operation were analyzed along with records for the years prior to the VSL system. Crash records must be analyzed for a minimum of three years with the system in operation in order to determine with statistical confidence if the safety along the corridor has improved. Therefore, in the future, crash records will be analyzed to determine the effectiveness of the VSL system on improving safety. In the meantime, crash records prior to the VSL system installation were analyzed to set the baseline crash history.

Crash record data from 10 and 5 years prior to the VSL system installation showed persistent crash problems along the corridor. During the study it became clear, that corridor between Peterson (MP 238.15) and Quealy Dome (MP 290.44) is prone to higher crash rates than other parts of the I-80 WY. Approximately 2,600 crashes occurred on the VSL corridor between January 1, 2001 and April 15, 2010 and there were minimum 22 crashes recorded by WYDOT per each mile along the corridor. The study also found that West MP 252 remained an accident prone spot with 86 crashes, which is the highest number for the corridor.

Most important variables that lead to a crash were found to be weather and road conditions, since the majority of crashes accidents have happened during severe weather conditions or on the icy/frosty/wet pavement.

The year after VSL system was implemented in February 18, 2009 was the period when Elk Mountain Corridor had the fewest crashes of any of the 10 years prior. During this time the total number of incidents and the number of injury crashes fell to 0.999 and

0.208 per Million Vehicle Miles Traveled (MVMT) respectively. These are the lowest crash rates in the last decade. The highest total crash rate occurred between February 18, 2007 and February 17, 2008. However, the number of fatal crashes remained consistent in the last ten years and was equal to three fatal crashes per year on average.

System Implementation

The VSL system use was analyzed for two winter time periods and one summer time period for five VSL sign locations in each direction (EB and WB). Analyses compared the various posted speeds to the frequency, cumulative duration, and average duration of each use of that particular speed. Data was also broken down by milepost as different speeds were implemented in varying frequencies and durations along the corridor. There is a clear preference of the TMC to implement speeds of 65, 55, 45, and 35 mph as opposed to 60, 50, and 40 mph. The VSL system is widely used throughout the year with typically long durations.

Additional analyses were done for four newly added mileposts, two in the eastbound direction and two in the westbound direction. These analyses were completed for the winter season from 2009 to 2010, although the speed sensors came online beginning on February 3, 2010.

Baseline Speeds

Analyses were completed on driver's speeds during "ideal" and "non-ideal" conditions. Ideal conditions were described by dry roads and wind speeds less than 45 mph. Because of the seasonal speed limit, there were two sets of data for this phase, a 65 mph data set and a 75 mph data set.

One of the goals of the Variable Speed Limit system (VSL) is to decrease the speed variation between the vehicles. When there is a large difference in speeds between vehicles, there become safety problems. Overall, the speed variation decreased between the 75 mph data and the 65 mph data, which shows that decreasing the speed decreases the speed variation. It seems that during the 65 mph data set, the average and 85th percentile speeds were much higher than the posted limit compared to the 75 mph data set. It seems like drivers were more disobedient of the seasonal 65 mph speed limit when the conditions were "ideal". The baseline speeds will likely become a modeling variable during Phase II.

RWIS Variable Analysis

The Road Weather Information System (RWIS) records a number of weather variables. The task was to figure which variables were significant to use in future. The data was split up into four storm events since there were issues encountered with running larger data sets.

The time of day has an impact on driver's speeds. Drivers drive faster during the day than they do at night. Surface status (SfStatus) was significant in three out of the four models. Drivers speeds are faster when the surface is dry than when there is moisture on the road. Visibility was significant in both Storms 3 and 4. Wind speed is also a factor that impacts driver's speeds. Storm 4 was the only event in which neither wind gust speed (WindGustSpeed) or average wind speed (AvgWindSpeed) were significant. In all other storm events, either one or the other is significant.

The variables that were deemed as insignificant were the wind direction, the relative humidity (RH), the dewpoint, and the temperature variables. These were

variables that even though they were often significant in the model are not variables that drivers appear to react to while they are driving.

Precipitation rate (PrecipRate) became a significant variable in the model that was run for a separate task to see if the VSL system was impacting driver's speeds. The PrecipRate variable was not available in the earlier data set used to estimate the other models.

For the 2009 winter storm event from October 15th to December 15th the data was not spilt into any storm events. The RWIS variable analysis was done for the entire period as a single file. Surface status, surface temperature, RH and dew point were significant in impacting the speeds of the vehicles in both the directions. The visibility variable was least significant possibly because of units issues (visibility is in feet and other variables are measured in miles).

For the storm that occurred during December 1st to December 2nd 2009, individual speed data was collected and RWIS variable analysis was done. It was found that surface status and precipitation type variables have the most significant impact on vehicle speeds. The other RWIS variables: surface temperature, RH and dew point have become significant variables.

RWIS Significance

From the modeling, it was found that the single RWIS station currently installed on the corridor does a reasonable job at describing the conditions along the corridor. Just as every storm event is entirely different, storm events hit different locations to varying degrees.

In this task, all the speed sensors were compared to the control sensor. The control sensor was located at Arlington and was used because the RWIS station was located closest to that speed sensor. The majority of the variables from each sensor model matched the control sensor variables. In Sensors 16 through 19 wind gust speed (WindGustSpeed) was not a significant variable, and relative humidity (RH) and Dewpoint were the other two that were common variables that did not match up with the control sensor. Even though the RWIS station does a reasonable job at describing the conditions along the corridor, it would be beneficial to have more RWIS stations along the corridor so that the weather conditions at each sensor are more accurately defined.

VSL Sign Significance

The initial model with both the eastbound (EB) and westbound (WB) variables found that the EB significance was much greater than the WB significance. Therefore, new models that split the speed sensor data by direction data records were run with separate variables to see what the significance was when each variable was modeled independently.

For winter 2009 modeling it was found that EB and WB variables have almost the same amount of impact on vehicle speeds. The coefficient of these variables varied from 0.587 to 0.857. These coefficients are interpreted as the VSL system impacting the observed speeds by lowering them 5.9 to 8.6 mph for every 10 mph of speed reduction posted on the signs. This observed speed reduction is in addition to the natural speed reductions due to observed weather conditions. It is clear from the results from the December storm event modeling that there was low speed compliance as the coefficient of EB and WB variables varied from 0.345 to 0.643.

Therefore, the VSL is impacting driver's speeds. This information is based off eight speed sensors and two months worth of data during the winter of 2009. Analysis must be done more extensively to see if this conclusion is consistent for all sensors along the corridor.

Individual Speed Analyses

To check how cars and trucks are reacting to VSL signs individual speed data was collected. Data was collected for the three mileposts 256.25, 273.15 and 289.5 for three different storm events occurring: December 1-2, 2009; February 3-4, 2010; and March 18-21, 2010. Collecting individual data requires sensors to be taken off-line from the program that runs the TMC speed map and therefore data from only three sensors was collected for limited time durations. The sensors selected to get observations from are at the beginning, middle, and end of the corridor. The original binned data does not give 85th percentile speeds; nor does it separate cars and trucks. The classification of vehicles was done based on the size of the vehicles. To examine the difference in speed behavior between cars and trucks the speed data was filtered into 5 minute and 15 minute periods. Graphs were drawn between 85th percentile speeds of cars, trucks and posted speed limits for two categories (5 minute and 15 minute).

In a similar way, to check for the speed deviation among cars and trucks, speed data was aggregated into 15 minute period and standard deviation was calculated. Graphs were drawn between standard deviations of cars and trucks. Statistical significance testing was done for both the difference in speeds and the difference in standard deviation for cars versus trucks. Statistical significance was found between car speeds and truck speeds. Cars were traveling faster than trucks. Statistical significance was also found

between the standard deviations of cars and trucks for the February and March storm events, where cars had a higher standard deviation. For the December storm event there was no statistically significant difference between the standard deviation of cars and trucks. In depth analysis was done by categorizing the entire storm event into four stages: Ideal, Transition, VSL implemented and Extended VSL. During these stages average speed, 85th percentile and standard deviation were found.

Speed compliance was defined for this analysis in two ways. The first was a *strict* definition that determined the percentage of vehicles that were observed going at or below the posted speed limit. The second was a more *lenient* definition where vehicles were considered compliant if they were going not more than 5 mph above the speed limit. The data was split into the way above mentioned. The results were shown that there was low speed compliance. Speed profiles were created to show vehicle speed versus the frequency of occurrence using the individual speed data in EB and WB directions. As predicted speeds were high during the ideal period then they begin to drop during the transition period. Speed variation was higher during the transition period compared to that of the VSL implemented period and speeds start to increase in the extended VSL period.

Data from a summer and winter ideal time period was analyzed to demonstrate how drivers have been reacting to the 65 mph seasonal speed limit. An ideal time period is one that occurs prior to a storm event; the VSL has not been implemented, and is during daylight hours. The maximum speed limit is in place during ideal periods, so the winter speed limit was 65 mph and the summer speed limit was 75 mph. The analyses from the ideal data sets demonstrated that during ideal periods cars typically drive faster

than trucks. Also, it was found that the 85th percentile speeds of vehicles in the summer and winter period were nearly the same, only a 1.5 mph difference, even though there was a 10 mph difference in the speed limit. Furthermore, the speed compliance rates were much higher during the summer period than they were during the winter period.

Control Strategy

To improve the efficiency of current VSL system on Elk Mountain corridor a draft model of control logic was designed. Control logic is a step by step procedure that allows the TMC operator to post speed limits that are timely and reasonable based on real time weather and speed data instead of relying on personnel in the field to initiate the change. The intention is not to fully automate the process. Therefore, verification of conditions and authorization of the recommended speed limits would still be done by TMC operators.

Development of draft VSL control strategy was done by analyzing the data that was collected from the October to December, 2009 time period and the individual speed data for the December 1-2, 2009 storm event. The data was categorized into 9 different bins based on observed speed and then sub categorized based on surface status and precipitation type. To observe the trend between the observed speeds and the candidate RWIS variables, graphs were drawn. Thresholds of RWIS variables that are statistically significant and following the same trend as of observed speeds are found by analyzing maximum, minimum, average and 85th percentile values.

The draft control logic was implemented in two stages:

1. Observed speed perspective
2. Weather variable perspective

In stage 1 the data which was merged from speed sensor data, RWIS data and VSL data will pass through quality checks. The 85th percentile speeds and the vehicle counts for every fifteen minute period were calculated. The data will pass through low volume filter and speed rounding filter resulting in a new suggested posted speed limits.

During stage 2 the data, after merging and passing through quality checks, passes through 9 sub threshold filters. The data which bypasses those sub filters will pass through visibility threshold filter, this filter will ensure that there is no missing data. 85th percentiles were calculated every fifteen minute period for the data that passed through all the filters. New recommended speed limits were obtained by applying the speed rounding filter to the 85th percentiles.

After obtaining the speed limits from both the speed and RWIS methodologies, the data should pass through a final filter which combines the two recommendations (if different). The Final filter:

- If the difference between speeds obtained from the RWIS perspective and speed perspective is greater than 15 mph then the RWIS limit should be used; otherwise the speed perspective limits (Stage 1) are used.

Phase II Project

Research on the variable speed limit corridor will continue with a 30-month Phase II project that will continue to monitor the implementation of a control strategy and decision-support system on the Elk Mountain VSL corridor. The Phase II project will also look at four proposed VSL corridors in other parts of the state. The four proposed VSL corridors are:

- I-80 between Green River and Rock Springs (MP 88 – 111). This project is expected to be let for bid in Spring 2010 and constructed by Fall 2010.

- I-80 between Laramie and Cheyenne (MP 316 – 356). This project is expected to be let for bid in Fall 2010 and constructed by Fall 2011.
- I-80 east of Evanston through the Three Sisters corridor (MP 7-28). This project is expected to be let for bid on Fall 2010 and constructed by Fall 2011.
- US 287 from Tie Siding to the State Line (MP 420 to 426). This project is expected to be let for bid on Spring 2013 and constructed by Fall 2014.

The work plan for the Phase II project is divided into the following 10 tasks:

1. Procurement and installation of speed sensors and RWIS for US 287 Corridor
2. Compilation and characterization of historical weather data for the Green River–Rock Springs, Cheyenne–Laramie, and Evanston–Three Sisters Corridors
3. Generation of baseline speeds in the corridor and determination of existing speed response to weather conditions for the Green River–Rock Springs, Cheyenne–Laramie, and Evanston–Three Sisters Corridors
4. Development of Decision-Support Systems for the Green River–Rock Springs, Cheyenne–Laramie, and Evanston–Three Sisters Corridors
5. Implementation of the Decision-Support Systems for the Green River–Rock Springs, Cheyenne–Laramie, and Evanston–Three Sisters Corridors
6. Compilation and characterization of historical weather data for the US 287 Corridor
7. Generation of baseline speeds in the corridor and determination of existing speed response to weather conditions for the US 287 Corridor
8. Monitoring of the Implemented Use of the Decision-Support Systems and Modifications as Necessary
9. Development of Decision-Support System for US 287 Corridor
10. Development of Generalized Methodology for Decision-Support Systems for Future Corridors.

Results from the Phase I project for the Elk Mountain VSL Corridor indicate that a decision support system to recommend speed limit changes is required to get necessary levels of speed compliance and reductions in speed variations. As the number of VSL systems in Wyoming increase, this need becomes even more important as operators at the WYDOT's Traffic Management Center (TMC) become responsible for a larger number of VSL signs. The second phase of this research proposes to study baseline conditions for weather and speeds for each of the proposed VSL corridors in order to develop a decision support system for each corridor. There are significant differences in the types of travelers, roadway variables, and weather on each of the corridors that warrant further research beyond the Phase I project. It is hoped from the second phase of this research that a general methodology for operations of all future VSL systems could be developed.

Table of Contents

Table of Figures

Table of Tables

Chapter 1 Introduction

Weather in Wyoming is often unpredictable and severe, causing problems for travelers. Motorists driving Interstate 80 (I-80) between the towns of Laramie and Rawlins, in the southern part of the state, can experience sections with ideal road conditions followed by sections of road that are nearly impossible to drive. Because the road conditions are not always consistent, driver's speeds are also not always consistent, causing many safety problems. Traffic accidents and roadway closures take a heavy toll in terms of lives, lost productivity, and wasted energy. In 1993, traffic accidents in the United States claimed 40,115 lives and injured an additional three million people. A cause cited in many of these accidents was 'speed too fast for conditions' (Placer, 2001).

The posted speed limit on I-80 for the section between Laramie and Rawlins is typically 75 miles per hour[1]. Under ideal weather conditions, the speed limit is reasonable for the geometric design of the interstate. When the weather worsens, driving the speed limit can be dangerous for the motorists. In poor road and weather conditions, it is the driver's responsibility to travel at a speed that is appropriate for the actual conditions. Since the speed selected is dependent on each driver, the speeds can vary widely. This variance in speed can cause safety issues.

Travelers rely upon traffic control systems, such as traffic signals, that have changed little since they were first developed decades ago. The same can be said of speed limits. Maximum speed limits are posted based on the geometric and traffic design features of a road under ideal conditions. Generally, this has little to do with actual real-

[1] In October of 2008 the Wyoming Department of Transportation implemented a seasonal speed limit of 65 mph from October 15th to April 15th of each year as an interim measure until the proposed variable speed limit system is fully operational.

time roadway conditions. Similarly, speed limit systems have been developed to control speeds based on conditions that may not reflect actual, real-time driver behavior or conditions. This can breed disrespect and eventual disregard for the messages. What is needed is a real time, environmentally accurate and responsive system that displays to motorists, safe driving speeds (Placer, 2001).

Determining an appropriate speed for the current conditions can be difficult for the driver. Equally difficult is for law enforcement agencies to enforce and cite someone going too fast for conditions. It is a difficult and subjective determination. In many cases, drivers are cited for going too fast for conditions only after the accident has occurred (Placer, 2001).

I-80 in southeastern Wyoming can carry 11,000 vehicles per day. On average, approximately half or more of those vehicles are trucks carrying freight. Truck drivers often have pressure from the freight carriers to travel as fast as possible to meet tight delivery schedules.

Another unique aspect about I-80 corridor around Elk Mountain is the often "invisible" hazard of high wind conditions. Since over half of the daily traffic on I-80 is trucks, high wind conditions can put the trucks at high risk of tipping over or being pushed of the road. The Wyoming Department of Transportation (WYDOT) posts high wind advisories on Dynamic Message Signs that advise drivers of the wind speed. However, some drivers may not know the effect that the advised wind speed will have on their vehicle. A University of Wyoming (UW) study into the high wind crashes on this segment of road found that slippery road conditions, such as ice and snow, actually reduced the likelihood of an overturning crash (Young & Liesman, 2007). It was

postulated by researchers that drivers reacted to the visible road condition and reduced their speed. High winds may be known to be hazardous, but do not necessarily lead to reduced speeds.

A comprehensive analysis of crash rates along the entire Wyoming section of I-80 was performed in 2006 by the University of Wyoming (Tomasini, 2006). The results can be seen in Figure 1-1, which shows that the section of interstate between Laramie and Rawlins has segments that have some of the highest crash rates. Most of the hazards that drivers experience on these sections are high winds, blowing snow, and icy spots.

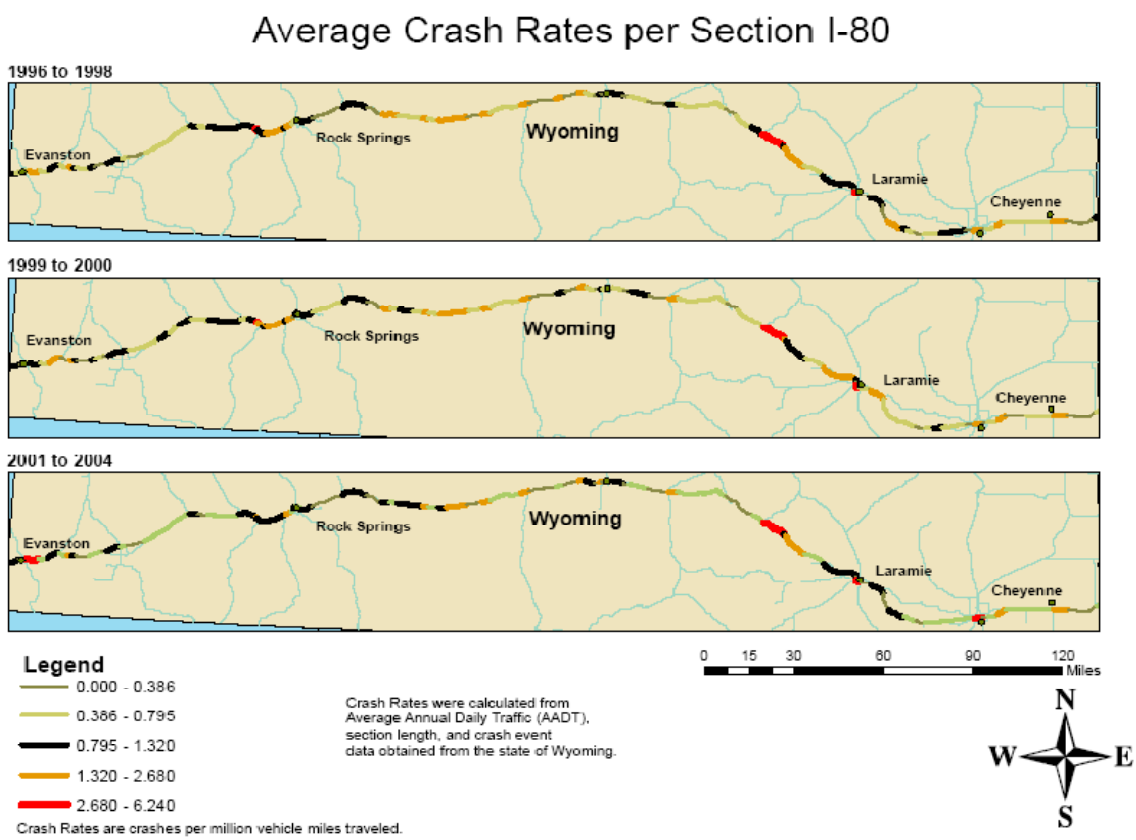

Figure 1-1: Average Crash Rates on I-80 in Wyoming

Closing the interstate is not only inconvenient for drivers but also has large economic impacts. Earlier research found that the average closure time of I-80 in

southeast Wyoming was eight hours long (Young & Liesman, 2007). Since I-80 is a main route for freight vehicles, this means that freight can sit in trucks for eight hours longer than normal if the roads are closed. The value of time for freight carriers for unexpected delay, such as those caused by weather and traffic crashes, is estimated very conservatively at around $370 per hour. This means that the cost for one truck during the average road closure is close to $3,000. An 8 hour closure results in a cumulative impact of almost $8 to $12 million in delay costs (Young & Liesman, 2007). Any operational changes that would result in even one hour of reduced closure would have considerable benefits, particularly when considering the frequency of closures in this area.

Variable speed limits (VSL) are one type of intelligent transportation system (ITS) that has shown promise for improving safety on roadways subject to adverse conditions (FHWA, 2007). VSLs are systems that change either the advisory or the enforceable speed limits of a roadway based on conditions such as weather, traffic volumes, incidents, or the presence of roadway construction. VSLs help reduce the variance in speed during any conditions.

1.1 Problem Statement

Weather creates many safety problems on I-80. Prior to this project, the ITS components that were available for drivers on I-80 between Laramie and Rawlins were a road weather information system (RWIS) and dynamic message (DMS) signs that are located at either end of the corridor (mileposts 234.6 and 311.1). WYDOT implemented a VSL system along the Elk Mountain corridor during February 2009. The VSL system included 20 variable speed limit signs at ten locations and 10 speed sensors. The VSL system was

expanded in the 2009-2010 winter season to include 8 additional variable speed limit signs in four new locations.

Research Objective

The objective of this research is to develop a decision support system necessary to effectively and consistently implement the Elk Mountain VSL system. This was done by analyzing historical weather and speed sensor data to determine the speeds that most drivers feel comfortable driving under various recorded weather conditions and by analyzing the individual speeds of cars and trucks separately to observe how they reacted to the posted speeds. The main purpose of the system was to reduce the speed variability in the corridor during adverse weather conditions. Reduced variability should result in fewer crashes and fewer and shorter road closures over the long term.

This report represents the research effort and consists of the research tasks outlined in the following section.

Research Tasks

Analysis of data from both existing and proposed ITS devices was done to determine the baseline operating conditions of the roadway. Historical weather data was analyzed to characterize the prevalent weather conditions. The installation of speed sensors was used to determine baseline speeds along the corridor for use in the development of the decision-support system for setting the variable speeds. The speed sensors were installed at locations near the proposed VSL sign locations along the corridor. The speed sensor data helped analyze how drivers are currently reacting to the weather conditions.

During first phase of the research project, the VSL signs were purchased, installed, and tested at the current posted speed limit in preparation for implementing the

VSL system. After analyzing the speed and weather data, a statistical model was developed to create the basis for a decision-support system that will aid WYDOT in operating the VSL system.

In summary, the major tasks involved in this research were to:

- Survey the State DOTs to see what VSLs have been implemented in the U.S.,
- Determine baseline speeds for various observed weather conditions,
- Analyze weather data to determine key variables and threshold values,
- Perform a preliminary analysis on how drivers react to the new VSL system,
- Develop a decision-support system for VSL system operation from the baseline weather and speed data, and
- Determine the effectiveness of the VSL system in reducing crashes and road closures (long term).

1.2 Report Format

The various tasks of this research will be broken down into the following chapters:

1. Introduction,
2. Literature Review,
3. DOT Surveys,
4. Project Description,
5. Data Sources,
6. VSL System Use,
7. Data Analysis,

8. Analysis of Individual Vehicle Speed Observations,
9. Draft Control Strategy, and
10. Summary and Conclusions.

Chapter two presents previous applications of Variable Speed Limit systems and summarizes the existing research results. Chapter three discusses a Variable Speed Limit Survey that was conducted to determine where other VSL systems were located in the country and to gain additional information on the purpose and operations of each system. Chapter four describes the sign and speed sensor locations. Chapter five describes the data collection and data sources for the project. Chapter six provides an analysis of how the VSL system was used. Chapter seven provides the data analysis as well as the results of the project. Chapter eight presents an analysis on the data collected for individual vehicle speeds. A draft control strategy is presented in Chapter nine. Chapter ten provides the summary and conclusions that were reached as a result of the data analysis.

Chapter 2 Literature Review

A variable speed limit (VSL) system is a type of Intelligent Transportation System (ITS) that has been implemented in a number of locations to provide drivers with appropriate speed limits based on real-time traffic, environment, and roadway conditions by means of variable message signs (Lee, Hellinga, & Saccomanno, 2004). In urban areas, ITSs are being designed to reduce congestion and ensure safer, quicker, less expensive, and more energy efficient travel (Shi & Ziliaskopoulous, 2002). While ITS began as mainly urban applications, recent years have seen a rise in the use of ITS in rural areas as well. In rural applications ITS is helping drivers travel more safely in low visibility conditions and poor weather conditions.

This chapter provides an overview of previous studies that have been performed on VSL systems. The first section discusses general issues with speed limits and speed variables. The second section looks in-depth at five previous studies that were conducted using variable speed limits that are the most similar to the proposed I-80 system. Since field studies are expensive, section three explores using simulation to analyze the road and set the speed limit. In order to be effective, the VSL the system must be reliable, so consequently section four considers issues with system reliability. Section five discusses system acceptance and whether drivers think the system is beneficial. The last section contains a summary of the chapter and conclusions.

2.1 Speed, Speed Limits and Speed Compliance

Speed is one of the major factors for the road design and can be defined in many ways like design speed, operating speed, posted speed, running speed, advisory speed and 85th percentile on a particular roadway. Strong relationships between design speed, operating

speed and posted speed are desirable and these relationships could be used to design and build roads that would result in observed speeds that are desired for a facility (Fitzpatrick, Carlson, Brewer, Wooldridge, & Miaou, 2003). The functional classification of any road is often partially defined by the speed limit of that road. Speed limits are set so that they provide information about what speed is reasonable and prudent to drive on a roadway. Speed limits are set after careful examination of different roadway features, roadside geometry and observed 85th percentile speed. After a serious crash has occurred, speeding is often considered as a major contributing factor, but there are a number of variables that contribute to drivers' speed selection such as visibility, skill of the driver, state of attention, fatigue of the driver and the drivers' perception (Hurwitz & Knodler, 2007).

Speed Limits

The 85th percentile speed is the "safe" speed as reflected in the judgment of most drivers based on the current environmental and traffic conditions of the roadway. The *Manual on Uniform Traffic Devices* (MUTCD) states that speed limits must be posted in 5 mph increments. The MUTCD also states that the speed limit should be set within 5 mph of the free-flow 85th percentile speed (Federal Highway Administration, 2003). The National Highway Traffic Safety Administration says that the 85th percentile speed on the speed limit signs is based on ideal conditions: good visibility, free-flowing traffic, and good weather (National Highway Traffic Safety Administaration, 2005).

A Policy on Geometric Design of Highways and Streets, 2004 edition states that where physical features of the arterial are the controlling factors for speed selection and where most drivers tend to drive the speed limit, then the maximum speed limit that can be posted is 75 mph. Another criterion given is that only a small percentage of vehicles

are traveling over the speed limit during ideal conditions (American Association of State Highway and Transportation Officials, 2004).

It is assumed that the majority of motorists tend to drive safely for conditions. Therefore, setting the limit to the 85th percentile captures this safe speed perception. And because it appears reasonable to the public, setting the speed limit near this point encourages voluntary compliance, resulting in more uniform speeds that contribute to minimizing speed variance and opportunities for vehicle conflict (Shi & Ziliaskopoulous, 2002).

However, the safety benefits of setting the speed limit to the 85th percentile speed may depend on the range of speeds: the narrower the speed dispersion, the greater the safety benefits. Although speed is often assumed to be the greatest contributing factor in crashes, many studies indicate that speed is more important as a determinant of crash severity, but not of crash occurrence. Instead, speed variance is associated with higher crash rates. Experience has shown that safety goes hand-in-hand with smooth traffic operation. Anytime the smooth traffic flow is disrupted, the probability of crashes is increased. Higher speed variance means more frequent lane changing, and many crashes happen during such actions (Shi & Ziliaskopoulous, 2002).

Rational Speed Limits (RSL)

Reducing the speed limits does not guarantee the reduction in the number of crashes that occurred due to high speeds. Low speed limits can lead to poor compliance as well as large variations in speed within the traffic stream (Srinivasan, Parker, Harkey, Tharpe, & Sumner, 2006). A study done for the Nebraska Department of Road (NDOR) showed that if the posted speed limits were set lower than reasonable speed limits then there was an

increase of 5 to 10 percent of accidents when compared to zones where the speed limits were reasonable (McCoy, 1993). For the study reasonable speeds were defined as those set by the NDOR Method that considered road, traffic, and environmental variables. Increased speed variance can also create more conflicts and passing maneuvers that can lead to more crashes. On the other hand increases in speed limits that are too high (i.e. beyond a reasonable level) might increase the number of accidents, so it is important that the recommended speed limits be credible and enforceable. Well-set limits can help improve the safety of the traveling public by establishing an upper bound on speeds and by providing consistent guidance to drivers (Fontaine, Park, & Son, 2007). Properly set speed limits can provide a critical way to improve the safety of a stretch of the road. Speed limits are selected to balance travel efficiency versus safety. The optimal balance depends on the type of road and the environment in which it exists. By definition, a rationally established speed limit is one that is based upon formal review and engineering study and is reflective of realistic roadway speeds, which are reasonable under normal travel conditions. These limits are those which improve public traffic safety by helping them to choose a reasonable and discreet speed depending on the traffic conditions, roadway conditions, prevailing vehicle speeds like 85th percentile speed, speed distribution data etc. Two previous research applications on rational speed limits are described in detail in the following sections.

Evaluation of RSL: Virginia Department of Transportation

An evaluation of rational speed limits case study was conducted by the Virginia Department of Transportation in 2004 to evaluate how drivers responded to appropriately

set speed limits (Fontaine, Park, & Son, 2007). The RSL was implemented in conjunction with a coordinated enforcement and education campaign.

The project location was selected to satisfy the criteria of operating speeds exceeding the posted 55 mph limit and geometric conditions that were appropriate for a higher speed limit. The researchers implemented the RSL in two test locations: US 29 bypass around Altavista, VA and US 58/220 bypass around Martinsville, VA. The Altavista test section was approximately 8.57 miles long with 5 interchanges and the Martinsville test section was 16.4 miles long with 8 interchanges. Engineering studies of the speed limits at both sites were conducted.

The speed and crash data was collected on the test sites and the results revealed that there was significant non compliance with the 55 mph posted speed limits at both locations. The 85th percentile speeds always exceeded 65 mph at both the locations. As there was no serious crash problem, the posted speed limit was increased from 55 mph to 65 mph along with an enforcement and education campaign.

The results showed that strict compliance with the posted speed limits improved from 5 to 10 percent before the project began to between 45 to 50 percent. Mean and 85th percentile speeds increased by about 3 to 4 mph and the proportion of vehicles travelling more than 10 mph over the limit decreased to 2 to 3 percent. The total amount of severe crashes declined by 20 percent (Fontaine, Park, & Son, 2007).

Rational Speed Limits in Gulfport, Mississippi

The objective of the Gulfport research effort was to set a new increased speed limit that was combined with publicized and targeted enforcement (Freedman, De Leonardis, Polson, Levi, & Burkhardt, 2007). The result was greater speed compliance, more

uniform speeds and improved safety. The test location was on US Route 49, near Gulfport, Mississippi for 7.5 miles long segment. On the test segment, the speed limits were raised by 5, 10 and 15 mph creating 5 speed zones of 35, 40, 45, 50, and 60 mph. The approach for setting the speed limits was based on work showing the 85th percentile to be an acceptable limit from the safety perspective (Freedman, De Leonardis, Polson, Levi, & Burkhardt, 2007). Data on speeds, crashes, citations and enforcements hours were collected for the before and after periods. The results showed that prior to the speed limit adjustments, approximately 55 to 90% of vehicles exceeded the speed limits. After the speed limits were increased, the proportions exceeding the new speed limits were low, but still in the range of 25 to 50%. The speed related crashes were declined by almost 30 percent, based on a comparison to just the pre-demonstration year.

Speed Compliance with Variable Speed Limits

Speed limits should be self regulatory and more practical so that driver compliance to speed limits is high (Freedman, De Leonardis, Polson, Levi, & Burkhardt, 2007). Higher the speed compliance there will be less speed variance there will be among the vehicles, which will result in fewer accidents. Many studies were conducted to evaluate the driver compliance to VSL (McMurtry, Saito, Riffkin, & Heath, 2009).

To examine the behavior of drivers with respect to variable speed limits Lee and Abdel conducted a driver simulator with 86 participants along an 8 km free way section during which they encounter VSL signs warning about the downstream speed changes (2008). The results showed that the presence of VSL had a statistically significant impact on the level to which drivers complied with downstream speeds.

A study conducted in a work zone on the I-80 Utah to evaluate the speed compliance in response to a work zone VSL. The results found that there was reduction in speed variance of 0.5 to 1.0 mph, down from 1.5 mph to 5.0 mph with the static signs (McMurtry, Saito, Riffkin, & Heath, 2009).

2.2 Variable Speed Limit Applications

Each VSL application serves a unique need at its location, looking at previous applications can demonstrate how a VSL system can address many different kinds of traffic problems. Figure 2-1and Figure 2-2 illustrate variable speed limit signs that are currently in use in two very different types of applications. Figure 2-1 is along a rural, interstate over a mountain pass and Figure 2-2 is in an urbanized area with congested roadway. The following section describes five existing VSL systems that illustrate the different types of VSL applications.

Figure 2-1: VSL Sign in Washington State

Figure 2-2: VSL Sign in Europe

Speed Uniformity

In the Netherlands, a study was performed to look at the effectivesness of using a VSL to reduce the difference between the average speed of the traffic stream and the existing speed limit.

The VSL system was installed in 1992 to improve speed uniformity on a rural section of the A2 Motorway between Amsterdam and Utrecht and is still in use. The system covers 20 km (12.5 miles) with VSL signs spaced approximately every kilometer. System inputs are measured using loop detectors, which are spaced every 0.5 km (0.3 miles), and the system has the ablility to detect incidents automatically. The standard posted speed limit is is 120 km/h (75mph), and the variable posted speeds are 50 (32 mph), 70 (43 mph), 90 (56 mph) km/h. The posted speed is determined by a system control algorithm that considers the average speed and volumes across all lanes at one-minute intervals. When an incident is detected, a speed of 50 km/h is displayed. If the speeds are posted with a red circle (as shown in Figure 2-3), they are enforced by photo radar. If posted without the circle, they are advisory.

Figure 2-3: Photo enforced speed limit sign

Results showed that the differences in volume, speed, and occupancy between and within the lanes became smaller and variations also decreased when variable speed control was implemented (Lee, Hellinga, & Saccomanno, 2004).

Limited Visibility VSL

A VSL system for low visibility was installed on the A16 motorway on a rural stretch of road outside of Breda, Netherlands to elicit safer driving behavior during foggy conditions. The system continuously measures the available visibility range, and in case of fog, appropriate speed limits are displayed (Horst, 1997).

A59 was used as a control location for the project. The speed limit was higher on the control road (75 mph), so the overall speed change on the control road during low visibility was compared with the experimental road section. The experimental system consists of thirty-seven signs along a 7.4 mile stretch of road. When low visibility was detected, the speeds would be lowered and the word "MIST" would be displayed on the sign over the lane.

There were twenty visibility sensors along the corridor that measured the visibility every minute. The freeway was two lanes, and there were dual inductive loop detector pairs in six locations. Inductive loops collected the following information about each passing vehicle:

- Lane number vehicle traveled in
- Time of day (0.1s)
- Speed
- Vehicle length

The headway, space headway, and time headway could be calculated from the inductive loop data. Other data that was collected for the project were temperature, air humidity, wind speed and direction, and the type and quantity of precipitation (Horst, 1997).

The data analyses done that the system has beneficial effects on speed behavior. With the system implemented, the mean speed decreased when visibility was limited by fog. On average, the speeds decreased by 5 to 6.2 miles per hour on the experimental road compared to the control road. In extremely dense fog (visibility less than 150 feet), the speed was much lower on the control road than on the road with the VSL system (Horst, 1997). This means that drivers were slowing down more on their own than with the VSL system when the visibility was bad. However, when this happens, there could be a higher speed variation between vehicles.

The difference in mean speed between the two lanes decreased when the system was in use. Therefore, the speed is more uniform along the entire road. With respect to the headway, space headway and the time headway, the results indicated safer behavior. When the relation between mean speed and number of accidents is used, a reduction of 3 miles per hour reduced the number of accidents by approximately 15 percent (Horst, 1997).

A similar study was conducted on a rural section of I-75 near Tiftonia, Tennessee. The reason for doing the study was a 99-vehicle crash that occurred in December of 1992 that resulted in 12 fatalities and 42 injuries. There was a history of severe crashes on the corridor as well (Federal Highway Administration, 2002).

The system was 30 km (18.6 mi) long and consisted of ten dynamic message signs, eight fog detectors, 44 radar speed detectors, highway advisory radio, and six swinging gates that could close the entrance ramps. A picture of the signs used along the corridor can be seen in Figure 2-4. As seen in the figure, there is space above the speed limit sign to place the fog warning (Federal Highway Administration, 2002).

Figure 2-4: VSL sign in Tennessee

There has been no formal analysis of speeds, but observations indicate that the average speed has been reduced by about five to ten percent. Since installing the system in 1993, there have been no crashes due to fog (Federal Highway Administration, 2002).

Michigan Work Zones VSL

Variable speed limits in work zones were tested in an urban setting, outside of Flint, Michigan. The basic objectives of this project were to design and deploy a viable VSL system in a work zone and then to evaluate the extent to which: 1) speed limit compliance

is affected so the credibility of the posted speed limits is increased, 2) safety is improved, 3) and the traffic flow is improved. The system monitored traffic flow and speed at specific locations, calculated necessary speed statistics, and displayed a speed limit on a designated VMS according to pre-established logic. Settings were different depending on weekday versus weekend and the type of construction that was occurring (MiDOT, 2003).

In work zones, the VSL sign is temporary, so the signs were mounted on trailers within the work zone. The master trailer was equipped with a weather sensor. There were several rainy days during the pre-deployment test in which the weather sensors sucessfully detected rain and reduced the posted speed limit properly in response to the conditions. The data also showed that the weather sensor detected ice on the pavement on several cold nights. In conclusion, the weather sensor correctly detected the conditions on the road (MiDOT, 2003).

Data was collected with and without enforcement personnel present. The following Measures of Effectiveness (MOEs) were used:

- Average speed at specific trailer locations,
- Difference between average speed and displayed speed,
- Travel time through the work zone section where the system was deployed,
- 85th percentile speed,
- Speed variance, and
- Percentage of "higher speed" vehicles.

Overall, it was found that the average speed of motorists appeared to increase through the deployment areas in most instances when the VSL system was operating.

This was primarily true when and where other factors, such as ramps, did not add to congestion or require that speed limits be kept low. The travel time through the VSL deployment areas decreased as well. With such short deployment areas, the time savings is small and unlikely to be noticed by the average driver (MiDOT,2003).

In some instances (e.g., off-peak periods), motorists seemed to respond better to the lighted variable message sign displays than to standard static speed limit signs. There was evidence suggesting that the percentages of high-speed motorists decreased when the VSL system was operating. The addition of enforcement personnel in the VSL deployment area seemed to have no effect on average speed, speed variance, or percentages of higher-speed vehicles (MiDOT, 2003).

The Michigan Department of Transportation found that there were positive effects on average speeds through the VSL deployment area (increased) and travel time (decreased). Effects on the 85th percentile speed and speed variance were either undetectable or inconsistent. The percentage of vehicles exceeding certain thresholds (e.g., 60 mph) did, however, decrease when the system was in operation. The presence of enforcement personnel in the deployment area appeared to have no additional or interactive effect (MiDOT, 2003).

Weather Related VSL

A warrant for installing a VSL system is in places with frequent poor weather conditions. In Finland, a study was done on the effects of weather-controlled speed limits and signs on driver behavior on a 14-km highway near Hamina (Rama, 1999).

Because of the high accident risk in winter, speed limits are decreased during the winter season in Finland. On most two-lane roads, the speed limits are decreased from

100 km/hr (62 miles per hour) to 80 km/h (50 miles per hour). The winter season limits are normally enforced from the beginning of November to the beginning of April (Rama, 1999).

Speed and headway data were obtained from loop detectors. The road and weather conditions at the loop locations were estimated using the data from the automatic road weather stations. In total, data was collected from five stations. The conditions were classified by the data from the automatic road weather stations into three categories, good, moderate, or poor (Rama, 1999).

The main analysis of driver behavior focused on the mean speed effects in different sign and weather conditions. Only cars travelling in free-flow traffic were included in the analysis of mean speeds. Cars were defined as driving in free-flow traffic when their following distance ahead was more than five seconds. On average, 57 percent of cars traveled in free-flow traffic on the experimental road (Rama, 1999).

The mean effect of lowering the speed from 100 to 80 km/h (62 to 50 miles per hour) was 3.4 km/h decrease in speed (2.1 miles per hour). The decrease in mean speed was 9.7 km/h (6.0 miles an hour) on the experimental road, whereas the decrease in mean speed was 6.3 km/h (3.9 miles per hour) on the control road (Rama, 1999).

"No rain" situations were regarded as road conditions not easily detectable as poor by the drivers. In 94.1 percent of the situations there was no rain or only light rain, and in 5.9 percent of situations there was moderate or heavy rain (Rama, 1999).

When there was moderate or heavy rain, the decrease in the mean speed caused by weather on the control road was greater than the decrease caused the VSL system on

the experiment road. Ninety-five percent of surveyed drivers indicated that they thought the variable speed limits were useful (Rama, 1999).

In the summer season, the speed limit was decreased from 120 km/h (75 miles per hour) to 100 km/h (62 miles per hour) if road and weather conditions were poor. The mean effect of the variable speed limit was a 5.1 km/h (3.2 miles per hour) reduction (Rama, 1999).

The analysis included vehicles driving in car-following situations, that is, vehicles with a maximum of five seconds between themselves and the vehicle ahead. The proportions of headways less than 1.5 seconds were calculated by the speed sensors. In general, the proportions were quite low (about 18 to 20 percent) because of the relatively low traffic volume (11,000 to 15,000 daily traffic volume) for the four-lane road. The effects of the VMSs on the proportion of the headways under 1.5 seconds varied from 1.0 to 6.6 percent (Rama, 1999).

The main results indicated that the weather-controlled system decreased both the mean speed and the standard deviation of speeds. On the control highway section the speed also decreased during adverse weather and road conditions, but the speed reduction was less than the VSL road and the speed variance increased. The concept of the weather-controlled speed limits and displays on the system was successful. The VMS/VSL system contributed to safer driving during adverse road conditions by decreasing the mean speed and the standard deviations (Rama, 1999).

When the sign for slippery road was displayed in addition to the decreased speed limit because of snow or ice, the speed limit reduction caused by the variable changeable message signs (VCMs) was smaller by 1.7 km/h (1.1 miles per hour). In some cases, the

speed limit was not reduced but the slippery road sign was displayed, for example when the right lane was in good condition but the left lane was slippery. The mean effect of the sign for slippery road was 2.5 km/h (1.6 miles an hour) (Rama, 1999). Figure 2-5 shows the results of the study with the overall effect that the experimental had over the control road.

Speed Parameter	Experimental Road Speed Limit= 80 km/hr	Control Road Speed Limit=100 km/hr	Effect km/hr
mean/free flow	-9.7	-6.3	-3.4
mean/free flow/no rain	-9.5	-4.2	-5.3
mean/total	-8.8	-6.3	-2.5
standard deviation	-0.8	2.3	-3.4
85th percentile	-8.2	-3.5	-4.7
15th percentile	-6.7	-8.2	1.5

Figure 2-5: Results from the Finland corridor study

The Washington Department of Transportation (WSDOT) installed a VSL system along I-90 between North Bend and Cle Elum, WA to improve safety and increase the availability of road and weather information to drivers. The VSL corridor is 17 miles long and passes over the Cascade Mountains through Snoqualmie Pass. The pass is 921 m (3021 ft) high and includes an 8 km (5 mi) stretch with a five percent grade (Federal Highway Administration).

The system is comprised of 13 light emitting diode variable message signs (VMS), six weather stations (RWIS) that collect data every 30 minutes, and 22 radar

speed detectors that provide output every five minutes. The system is typically operated during the winter months from November to April. In the summer, it is used to support the construction and maintenance activities (Federal Highway Administration).

The decision to reduce the speed limit is based on feedback from the RWIS stations, snowplow operators, and the State Patrol. The speed limit is 65 mph on the pass when the conditions are ideal. When the roadway conditions become worse, the speed limit is lowered in increments of 16 km/h or (10 mph). The speed depends on whether traction tires are advised (89 km/h, 55 mph) or required (72 km/hr, 45 mph), or whether chains are required (56 km/h, 35 mph). WSDOT has also developed a matrix decision support system of speed advisories that takes into account the visibility of the road or other severe weather. The computer considers all the inputs and recommends a speed which is then checked by an operator (Federal Highway Administration).

Another aspect of this study was a driver simulation. The goal of the driver simulation was to assess the drivers' needs for variable message information (Dynamic Message signs (DMS) and VSL signs). The variables that were analyzed were mean speed and the derivation for the mean speed. The simulation required the drivers to maneuver through the system, but the only other vehicles that the driver encountered on the road was snowplows. The study was done with people who only saw the DMS, drivers who had in-vehicle traffic advisory systems (IVU), drivers who had the IVU and could see the DMS, and then drivers without any information systems (Ulfarsson, 2001).

When the messages in the simulator indicated fair-weather conditions ahead, the results were that drivers traveled at a higher speed than if the message was not displayed.

Drivers who received a message that displayed poor-weather conditions ahead obeyed the posted speed and drove slower than those who didn't receive the message.

The conclusion from this study is that drivers who receive information concerning the road conditions tend to have a higher speed deviation than those who don't receive the information. The study found that speed deviations were highest among the IVU and DMS drivers. This shows that drivers put their trust in the system when poor-conditions are reported, but that drivers travel at higher speeds when the report does not advertise problems (Ulfarsson, 2001).

Another finding from the study was that an inaccurate message may prove to be more dangerous than no message at all. It was found during the study that drivers without the system traveled the speed that they felt was safe and didn't put their faith in the simulation system (Ulfarsson, 2001).

A survey was given to all those who participated in the driving simulation. The survey found that the driver's perception of the conditions is the largest contributing factor influencing their speed. Driver's indicated on the survey that they would only obey the speed limit if the conditions warranted (Ulfarsson, 2001).

Overall, it was found that VSL and IVUs change the driver's behavior, but often cause a larger speed differential that puts those on the road at higher risks for accidents (Ulfarsson, 2001).

Speed and Headway

Roads in Finland can be dangerous in the winter because of snow and ice accumulation on the roads. It is estimated that the risk of accidents in the winter is 20 times higher than in the summer. Maintenance crews cannot provide weather-related maintenance (i.e.

snow removal, salting, sanding) immediately, and studies show that accident risks are 12 times higher during the hour before maintenance actions are taken than before the road conditions deteriorate.

The purpose of the Finland VSL system is to provide drivers with real-time information about poor-road conditions, especially during the period from the first indication of a problem and the start of maintenance actions (Rama & Kulmala, 2000).

The test was done at three different rural locations in southwest Finland. Site one was at Eurajoki, site two was at Koski, and site three was in Salo. The speed limit was 80 km/h (50 mph) at each site. Site one contained a minimum headway sign and a slippery road condition sign (shown in Figure 2-6), but sites two and three only had the slippery road condition sign. Data from Sites 1 and 2 included two winters, while data from Site 3 was for one winter (Rama & Kulmala, 2000).

Figure 2-6: Signs posted at Site 1

Data was collected using loop detector based traffic monitoring stations (TS). The project used three TS. TS1 monitored the driving behavior before the drivers reached the signs, and TS2 and TS3 recorded data downstream from the sign. The behavior at TS1 should indicate the "baseline" behavior in poor-weather conditions, and the difference between that and the behavior at TS2 and TS3 should indicate the overall effects of the system (Rama & Kulmala, 2000).

The experimental design included signs that flashed and those that had steady display, to see which type of sign had more impact on the driver. Six road condition messages were displayed, as follows: 1) steady slippery road condition sign, 2) flashing slippery road condition sign, 3) minimum headway sign with the steady slippery road condition sign, 4) minimum headway sign with the flashing slippery road condition sign, 5) minimum headway sign only, and 6) a blank sign (nothing) (Rama & Kulmala, 2000).

The speed analysis included only the vehicles that were traveling in free flow conditions (5s or greater of headway to the vehicle ahead). In good-weather conditions, the mean speeds at each location are as follows: TS1 at site 1was 87 km/h (55 mph), TS2 located at site 2 was 92 km/h (58 mph), and TS3 at site 3 was 84 km/h (53 mph). In poor-weather conditions, the speeds were lower on average by 5 km/h (4 mph) (Rama & Kulmala, 2000).

The results showed that the steady slippery road sign with the minimum headway sign decreased the speed of vehicles at sites 1 and 2 by an average of 1.2 km/h (1 mph). A larger decrease in speed (2.1 km/h, 1.5 mph) was seen using the flashing slippery road sign with the minimum headway sign at sites 1 and 2. Site 3 saw an increase of 1.1 km/h (1 mph) when using the flashing road sign in conjunction with the minimum headway sign.

Figure 2-7 shows the effects that the signs had on the mean speed for the cars that were travelling in free flow traffic, and the parenthesis shows the effect for total traffic flow (Rama & Kulmala, 2000).

Site	VMS	Speed effect (km/h) (TS2-TS1)			
		Winter 1		Winter 2	
1	Slippery road condition sign (steady) and minimum headway sign	-0.9	(-0.5)	-0.8	(-0.1)
	Slippery road condition sign (flashing) and minimum headway sign	-2.2	(-2.2)	-1.9	(-1.8)
	Minimum headway sign	-1.1	(-1.2)	-1.0	(-1.1)
2	Slippery road condition sign (steady)	-1.8	(-1.5)	---	(-0.6)
	Slippery road condition sign (flashing)	-2.3	(-1.7)	---	(-1.3)
	No message	+0.1	(-0.3)	---	(-0.2)
3	Slippery road condition sign (steady)	---		+1.4	(+1.2)
	Slippery road condition sign (flashing)	---		+0.8	(+0.5)
	No message	---		+0.1	(+0.1)

Source: Rama and Kulmala (2000)

Figure 2-7: Effects of signs on driver speed

The headway analysis showed that the minimum headway sign that was shown at Site 1 caused significant changes in the percentage of small headways. Before the study, 25-35% of drivers had less than a 1.5 second headway in good conditions and 16-18% in slippery conditions. When the signs were put up during the study, it was found that 16-18% of drivers drove with headway less than 1.5s in good road surface conditions and 13% in slippery conditions. Therefore, the minimum headway sign affected headways in the desired manner. Figure 2-8 shows the change in the percentage of drivers with headways between 1.5 and 5.0s (Rama & Kulmala, 2000).

Site/Road Condition	Change in percentage of short headways	
	Winter 1 (%)	Winter 2 (%)
Site 1/good condition	-38	-28
Site 1/possibly slippery	-47	-37
Site 1/verified slippery	-37	-31
Site 3/possibly slippery	---	-12

Source: Rama and Kulmala (2000)

Figure 2-8: Change in the percentage of drivers with headways between 1.5 and 5.0s

It was deemed that, overall, even though the decreases in speed were small, the accident risk decreased. The minimum headway sign influenced the headway in the desired manner, because the percentage of people with small headways decreased (Rama & Kulmala, 2000) .

The flashing signs affected driver behavior the most. This is believed to be true because flashing tends to indicate danger, although it was found in the study that the meaning of the flashing sign is not always clear to the driver (Rama & Kulmala, 2000).

2.3 Simulation

Field evaluations are time-consuming and prohibitively expensive, and the analyses of before-and after field observations are often hindered by the presence of confounding effects, such as the effects of other actions taken during the speed limit changes (e.g., intensive speed enforcement) or other factors that may have affected the safety (e.g., changes in traffic volume) (Lee, Hellinga, & Saccomanno, 2004). Simulation models are tools that are used to overcome the limitation of the field observation. Simulation models are classified as being microscopic or macroscopic.

Macroscopic

Macroscopic models consider the movements of individual vehicles as aggregated groups. With this type of model, the theory is clearly defined by mathmatical relationships, and assumptions about individual driver characteristics are not made. A macroscopic model can be used to understand the general relationship between the speed limit changes and the associated impacts on the traffic flow. A macroscopic model considers the entire system as a whole, and cannot look at individual interactions between individual vehicles.

The macroscopic model has been used in many urban research projects. Sailer et al. formulated a mathmatical expression for the speed-density relationships as a function of speed limits (1999). This research predicted the impact of the VSL system on the distribution of traffic speed, finding that free-flow speeds decrease with speed limits. Another project done by Alessandri et al. resulted in a model that could estimate the traffic density and established the variable speed limits based on the estimated density. They found that the variable speed limits can prevent congestion and increase the average speed along the corridor (1999). Breton et al. developed a traffic simulation model that took the VSL into account and found that the reduction of speeds reduced the effects of a shock wave traveling upstream by creating a low-density wave traveling downstream. They concluded that, although variable speed limits slow the traffic down temporarily, the flow can be increased by reducing travel times as a result of avoiding sudden speed changes (2002).

Microscopic

Microscopic models consider the movement of each individual vehicle. Microscopic models allow changes to be made in the posted speed limits on each section, making crash estimation in real time possible. Microscopic models allow for instantaneous traffic flow for individual vehicles that can be aggregated to give the speeds and volume of the entire stream (Lee, Hellinga, & Saccomanno, 2004).

In a microscopic model, a posted speed limit can be defined as the maximum allowable speed. Since drivers do not always comply with the speed limit, the model simulates random driver compliance with the posted speeds. The mean speed is designed

to be slightly above the posted speed limit. The model also considers the aggressiveness of each driver since this normally varies as well (Lee, Hellinga, & Saccomanno, 2004).

Hawkins et al. found that VSL systems tended to make drivers more aware of and more obedient to the speed limits because the speeds were appropriate for the conditions. It was also found that a variable speed limit system must address the following four strategy control factors:

1. When should speed limits be changed,
2. How frequently can the speed limits be changed,
3. How long can the speed limit changes be in effect, and
4. If the speed limits should be changed, should they be increased or decreased, and by how much? (1999)

Florida-Microsimulation

A Florida study looked at Interstate-4 in Orlando, using micro-simulation to determine if crash likelihood could be reduced using VSL in an urban city (Abdel-Aty & Dilmore, 2005). When there are crash problems, it seems the problems lie in large variances in speed and inappropriate headways. One of the biggest issues considered in the study was crash location and crash migration upstream and downstream of the crash location.

Intuitively, crash potential would seem to be higher upstream of the detector which indicates low speeds on high-speed roadways. The results from Abdel-Aty et al's algorithm in this case can be interpreted to mean that packs of faster moving vehicles coming into contact with slower traffic result in high crash potentials (Abdel-Aty & Dilmore, 2005).

After the speed limits have been changed, there are high-speed vehicles that reduce their speed. It was found that using Variable Message Signs (VMS) to warn of impending speed limit changes would make the change in speed more gradual (Abdel-Aty & Dilmore, 2005).

Determining if the crash potential will occur at a downstream station is a little more challenging. Increasing the speed limit could clear large queues, but the roadway geometry downstream (number of lanes, or curves) could induce a bottleneck that causes queues to form in different locations. The results showed that crash potential appears to relocate to the detectors downstream of the detector of interest if speed limits are increased. Geometry could have played a role in the results because there was a curve on the stretch being analyzed (Abdel-Aty & Dilmore, 2005).

Safety was increased by simultaneously implementing lower speed limits upstream and higher speed limits downstream of the location where real-time observations indicate that crashes may have occured. There was improvement found in the cases of medium to high speed regimes on the freeway, but there was no substantial safety benefit from applying VSL in congested situations (Abdel-Aty & Dilmore, 2005).

Another factor that was considered in the research was travel time. A reduction in time travel was found, which increased the efficiency of traffic flow on the freeway (Abdel-Aty & Dilmore, 2005).

It was found that, through the use of VSL and strong enforcement (video cameras or police officers), the number of crashes could be reduced by as much as 28% over 18 months. The effect was attributed not only to a smoothing of traffic conditions over

longer distances, but also to a reduction in the number of lane changes made during congested periods (Abdel-Aty & Dilmore, 2005).

2.4 Assessment of System Reliability

Manual observations of weather and road conditions were collected, and friction measurements were carried out in a research effort by Rama to assess the reliability of VSL systems. A total of 139 situations were analyzed on Highway E18 in Finland between Kotka and Hamina. Most of the manual observations were made when the weather and road conditions were becoming worse (Rama, 1999).

Manual observations involved two factors: the speed limit or warning that was actually displayed and the appropriateness of the signing as was estimated by the manually collected data. The speed limits were based on the data that was collected by two weather stations. The weather data was then classified as poor, moderate, or good. The ratings were based on type of precipitation, precipitation intensity, road surface conditions, visibility, and wind speed (Rama, 1999).

In 70 percent of the cases, the speed limit and the use of the sign for slippery road were deemed to be appropriate. Furthermore, the results indicated that there was a tendency to use speed limits that were too high. This conclusion was reached by comparing the posted speed limits to the speeds that the drivers were traveling. In 26 percent of the cases, the speed limit was assessed to be too high, or the sign for slippery road was not displayed when it should have been. In contrast, the actual speed limits were seldom too low for the conditions (Rama, 1999).

2.5 System Acceptance

Weather-controlled road signs and displays are designed to influence driving behavior and improve road safety without increasing disrespect for the posted speed limit. A study was done in Finland to investigate driver acceptance of the weather-controlled road signs where road conditions change frequently and rapidly (Luoma, 1997).

During the project duration, 590 drivers were interviewed at 3, 4, 11, and 13 months (January, February, September, and December) after the introduction of the new system. The survey was conducted at the rest area that was near the end of the project. On average by month, 82 percent of those surveyed were male, and the mean age was 42. The majority of those surveyed passed the site at least once a week during the survey period (Luoma, 1997).

It was found that drivers recalled the variable message signs somewhat better than the static (fixed) signs. The results also indicated that many drivers knew the variable speed limits; suggesting that a substantial portion of the drivers pay somewhat more attention to the variable signs than to the regular signs. During the survey period, 93 percent of drivers responded that they knew that speed limit changes were based on weather and road conditions (Luoma, 1997).

On average, 81 percent of drivers indicated that the prevailing speed limit was appropriate for the conditions of the road. Drivers were asked to evaluate the road conditions on their own using the three different ratings: poor, fair, and good. The results indicated that when the speed limit was low (50 mph), the majority of the drivers estimated that the road conditions were poor; no one estimated them as being good. In comparison, only 1 percent of drivers estimated the road conditions as being poor when the speed limit was high (Luoma, 1997).

Drivers felt that the VSL systems provided more up to date information than the regular warning signs. It was found that the information on regular warning signs was considered to be irrelevant by drivers (Luoma, 1997).

The system in Finland used a sign to display images such as slippery when wet or the current temperature when adverse conditions were present. Only a small percentage of the drivers answered that the slippery road sign or the temperature display in addition to the VSL signs influenced their driving. The researchers felt that this number was low and did not reflect actual behavior when the driver was on the road. They concluded that more research needed to be done (Luoma, 1997).

Overall, it was found that drivers feel that the VSL system is successful. Ninety-five percent of drivers find that the VSL established in accordance with prevailing road conditions are useful and enhance roadway safety (Luoma, 1997).

2.6 Summary and Conclusions

Variable Speed Limit systems have been utilized in many different situations and, from the results given in the literature, it appears that they are effective. The first thing that must be done prior to implementing a VSL is to decide what purpose the system needs to fulfill. The applications that were reviewed in this section included diminishing the difference between the posted speed and the mean speed, and warning drivers about low visibility, crash likelihood, work zones, and poor weather conditions. It found that in each application, the Variable Speed Limit system was beneficial.

Chapter 3 DOT Surveys

Variable speed limit (VSL) systems are a relatively new Intelligent Transportation System (ITS) application in the United States. VSL systems have been studied in several locations in Europe, but there has not been much research published on the systems in the United States. The Wyoming Department of Transportation is implementing its first VSL system on Interstate 80 (I-80) between Laramie and Rawlins, Wyoming. The system will be rural and the speeds will typically be lowered when the conditions warrant. The purpose of this survey was to gain insight into the permanent VSL systems currently in use in this country. The main objectives were to determine where other VSL systems were located and to gain additional information on the purpose and operations of each system.

Surveys were sent to the other forty-nine states departments of transportation through e-mail. The survey consisted of twelve questions aimed at providing a general overview of each VSL system. The survey can be found in Appendix A. The twelve questions are given below.

1. What State are you responding for?
2. Are you using a Variable Speed Limit system in your state? (If yes, please continue. If no, thank you for your participation.)
3. What corridors are you using the Variable Speed Limit system on? (Please provide the Route and the approximate mileposts)
4. How many signs do you have on the corridor? What type of signs are they?
5. Are you using the Variable Speed Limits in a rural or urban setting?

6. What real-time variables are you taking into consideration (e.g.: vehicle speeds, weather conditions, etc)?
7. What specific [weather] and [speed] variables are being monitored?
8. Are there threshold levels associated with these variables related to implementing variable speeds? If so, what are the thresholds?
9. Is dispatcher approval/verification necessary before the system is activated?
10. Are your signs overhead or side mounted?
11. Do you feel that your Variable Speed Limit system is working on the corridor?
12. Have any formal evaluations on the effectiveness of the system been performed?

3.1 VSL Survey Responses

The following is a summary of the responses to each question.

1.) What State are you responding for?

This question was used to identify which state was responding. All 49 states responded.

2.) Are you using a Variable Speed Limit system in your state? (If yes, please continue. If no, thank you for your participation.)

This question allowed each state to respond whether their state had a system, and if so, what type of system they had. There were three categories of systems that states said that they had: permanent systems on their interstates, work zone systems, or school zone systems. Table 3-1shows the states that have each system. No state has all three systems.

Table 3-1: Types of systems in each state

Type of System	States
Permanent System	Alabama, Colorado, Delaware, Florida, Maine, Missouri, New Jersey, Pennsylvania, Tennessee, Virginia, and Washington
School Zone	Hawaii, Kansas, New Hampshire, Montana, and Vermont
Work Zone	Illinois, Michigan, New Hampshire, North Dakota, Oregon, Washington

None of the states that had only school zone or work zone VSLs answered the remaining questions. The responses for questions three through twelve, for the eleven states with permanent VSLs, are summarized below.

3.2 Description of VSL Systems

The Alabama Department of Transportation (ALDOT) has one VSL system in their state. The system was destroyed by Hurricane Katrina a couple of years ago but is expected to be up and running around August 2009. The system is located on a nine-mile section of I-10 (MP 26 to MP 35). The VSL system is being used in an urban setting and there are 24 side-mounted LED signs along the corridor. The real-time variables that are monitored are weather and congestion. The specific variables that are being measured are visibility and vehicle speed. Dispatch approval is required before changing the speed posted on the sign. ALDOT said that their system worked well before hurricane Katrina struck.

The Colorado Department of Transportation (CDOT) has several VSL systems located on I-70. Heading eastbound (EB), the VSL system is 72 miles long, beginning at MP 177.4 and ending at MP 249.4. Heading westbound (WB), the current system is 32.9

miles long, beginning at MP 221.0 and ending at MP 253.9. The current system has 15 side-mounted LED signs in both directions but they plan to expand their system. The VSL system is located in a rural setting. It is not based on real-time variables, but it is used when the chain laws are in effect. Because of this, no specific thresholds are needed. However, verification is necessary to change the speed limits. When the VSL is in effect the speed limit on I-70 is lowered from 65 mph to 55 mph.

CDOT just implemented this system, so they do not have data to support whether or not it works. CDOT said in the survey that there are three more signs that they plan to install. One sign will be installed heading EB within the already established system. Two signs will be installed heading WB located at MP 197.1 and MP 219.9, which will make the WB VSL system 56.8 miles long.

The Delaware Department of Transportation (DelDOT) has a VSL system that is located on I-495. Interstate 495 is a six-lane bypass that goes around the city of Wilmington, Delaware. The system begins at the Pennsylvania state line and ends south of Wilmington. There are 23 side-mounted signs on the corridor that are VMS boards inset into black on white speed limit signs. The VSL system is located in an urban setting. The speed limit is lowered based on incidents and weather conditions. Incidents are crashes or disabled vehicles that cause the traffic on the roadway to slow down. The weather variables that are monitored include heavy precipitation, high winds, and reduced visibility. The pavement surface conditions that are monitored are ice and/or snow on the road, black ice, and/or materials spilled on the roadway. The Chief Traffic Engineer decides whether or not a speed limit change is warranted and sends the request to the Delaware State Police. DelDOT said in the survey that they feel their system

works. Their maintenance, construction and fire/police divisions view this system very favorably, but no formal system evaluations have been completed.

The Florida Department of Transportation has one VSL system in their state. Interstate 4 (I-4) provides a crucial link between Tampa on the gulf coast and Daytona Beach on the east coast. The system is located on the I-4 corridor along a ten-mile section in downtown Orlando (MP 79-89). The system is located in an urban setting and consists of 20 side-mounted LED signs. Figure 3-1 shows a picture of the VSL signs located on the corridor.

The system changes the speed limit based upon lane occupancy and vehicle speed. The thresholds for the system are based on three levels of traffic flow: free flow, light occupancy, and heavy occupancy. Each level has an Adjustment and a Recovery Threshold. The pair of boundaries provides "wiggle" room to prevent the system from bouncing back and forth as it passes a barrier. The Free Flow Adjustment is 1% occupancy and the Recovery Threshold is 13% occupancy. The Light Occupancy Adjustment Threshold is 17% occupancy and the Recovery Threshold is 25% occupancy. The Heavy Occupancy Adjustment Threshold is 28% occupancy and the Recovery Threshold is 99% occupancy. The system requires dispatch approval/verification before being activated. The system has not yet been utilized, so no formal evaluations have been conducted.

Figure 3-1: VSL sign on corridor in Florida

The Maine Department of Transportation (MaineDOT) has two VSL systems in their state. The first system is on the I-95 corridor and is 81.9 miles long (MP 110-191.9). The second system is on the I-295 corridor and is 41.2 miles long (MP 2.8-44). I-295 is a north-south system that branches off of I-95 for approximately 50 miles and then ties back into I-95. It provides access to Portland, Maine. The system is used in a rural setting, and there are 48 side-mounted radio-controlled LED signs.

The speed limit is lowered based on road conditions and travel speeds. Specific weather variables that are monitored include precipitation types and amounts, speed drops of more than 20 mph and other incidents can cause a change in the VSL. Speed readings are collected at ten minute intervals. The system attempts to set the posted speed to a value that is within 5 mph of the average speed on the highway segment. Alarms ring if the speed drops 20 mph or more. The system reads the real-time average speed of vehicles on that highway segment and then dispatchers validate any events that are taking place with on-site DOT crews or state police before activation.

This winter is the first season of implementation, so there have not been any formal reviews done on the system. One thing that MaineDOT is struggling with is

providing speed limit information in a timely manner and developing a protocol for turning the VSLs off when the road segment reaches an acceptable Level of Service (LOS).

The Missouri Department of Transportation (MoDOT) activated their only VSL system in May 2008. The system is located on I-270, which is located west of St. Louis. The system runs the entire length of the corridor of I-270. There are 70 solar-powered LED signs along the corridor. The real time variable that the VSL is based on is lane occupancy. Weather can be monitored, but weather alone will not currently result in a reduction in the VSL. There are no specific thresholds associated with the system. Dispatcher approval/verification is necessary before the system is activated. Occupancy increases just prior to a breakdown in traffic flow. The operator monitors the occupancy and decides to lower the speed limit. MoDOT said in the survey that they feel that the system is successful. However, the system is in its infancy, so sufficient has not been data collected to prove this.

The New Jersey Turnpike Authority is in charge of VSLs on two roadways in New Jersey. The first system is on I-95 and is approximately sixty-two miles long. The second system runs the entire length of I-78. There is a total of 109 static panels with changeable speed flip segment/disks between the two corridors. Figure 3-2 shows a picture of both types of VSL signs along the corridor. If the corridor has three or more lanes, the VSL sign is mounted overhead, and if the corridor has two lanes then the VSL sign is side mounted. Each VSL sign is adjacent to an Emergency Speed Warning sign that gives six conditions associated with the speed change. The six conditions are: an accident, congestion, construction, fog, ice, and snow. The Turnpike Authority is

currently replacing the current signs with static panels with LED. Since the systems are located over such long distances, they are located both in urban and rural settings.

The New Jersey Turnpike Authority feels that the speed limits are working on both corridors. The real-time variables that the VSL is based on are weather, down-stream incidents (congestion/accidents), and construction. The weather conditions that are monitored are fog, ice, and snow. The shift supervisor verifies with the state police for a visual observation before the system is activated. The speeds allowed for the VSLs are 55-30 mph, reduced in 5 mph increments. The thresholds for the system are given in Table 3-2.

Table 3-2: Thresholds for New Jersey Turnpike VSL

Condition	Speed Limit
Accident within 2 miles of a sign	45 mph
Congestion within 2 miles of a sign	45 mph
Visibility within 2 miles of sign 500-800 yards	55 mph
Visibility within 2 miles of sign 300-500 yards	50 mph
Visibility within 2 miles of sign 200-300 yards	45 mph
Visibility within 2 miles of sign 150-200 yards	40 mph
Visibility within 2 miles of sign 100-150 yards	35 mph
Visibility within 2 miles of sign less than 100 yards	30 mph
Snow within 2 miles of a sign	Maintenance Crew advises
Spot Salting of an affected area	50 mph
Full Salting of an affected area	45 mph
Plowing of an affected area	35 mph

Figure 3-2: **Picture of VSL sign in New Jersey**

The Pennsylvania Turnpike Commission is in charge of a VSL system on the PA 76 Toll Road. This east-west highway serves most of Pennsylvania's major urban areas, including Pittsburgh and Philadelphia. The system is ten miles long, beginning at MP 162 and ending at MP 172. The system consists of 28 LED signs that are side mounted. The Turnpike Commission adjusts the speed limit based on visibility. Speed limits are related to visibility levels that were based on the stopping sight distances taken from the ASHTO Policy of Geometric Design of Highway and Streets. Road Weather Information Systems (RWIS) determine visibility in fog prone areas. Dispatcher approval/verification is necessary before the VSL system is activated. The Pennsylvania Turnpike Commission said in the survey that the VSL system is working on this corridor, but no formal evaluation has been performed.

The Tennessee Department of Transportation has one VSL system in their state. The system is located on a ten mile section of I-75 in Bradley and McMinn County (MP 29 to MP 39). Interstate 75 enters the east Tennessee region from Georgia, goes through Knoxville, and then climbs into the Cumberland Mountains before crossing into Kentucky. There are two side-mounted LED signs located along the corridor that are changed when visibility is poor. When fog is detected on the corridor and the visibility

drops below 1320 feet (ft), the system goes into a preliminary mode. The overhead DMS displays a message of Fog conditions, but the speed limit is still 70 mph. When any other thresholds are met, the dispatcher activates the DMS with the appropriate message and lowers the VSL. The thresholds for the system are given in Table 3-3.

Table 3-3: Thresholds for Tennessee VSL system

Visibility Distance (ft)	Speed posted on VSL signs
>1320	70 mph
1320>Visibility>480	55 mph
480>Visibility>240	35 mph
<240	Corridor closed and traffic detoured

The Virginia Department of Transportation (VDOT) has VSL systems that are either in place, will be in place soon, or are in the planning stages. One of their systems in on corridor I-64 for traffic traveling through the Hampton Roads Bridge Tunnel, beginning at MP 268.3 and ending at MP 274.1. Another system is on I-664, for traffic traveling through the Monitor Merrimac Bridge Tunnel traffic, beginning at MP 5.8 and ending at MP 11.7. The third VSL system in Virginia is on I-264, for traffic traveling through the Elizabeth River Downtown Tunnel, beginning at MP 5.9 to MP 7.4.

The Virginia Department of Transportation is currently in the process of deploying a temporary work zone VSL system on I-95 between MP 171.93 to MP 178.56 and is looking into putting a system on I-64 from MP 97.27 and MP 107.22 (Afton Mountain) to combat fog issues on the corridor.

There are a total of 12 sets of side-mounted LED signs split between the three systems. The systems monitor and change the speed based on lane occupancy, incidents, and weather. The thresholds are based on mobility levels on the corridor. The mobility factor for each corridor with VSLs is used to select a speed limit from a "VSL Mapping

Table" which contains a set of speed limit patterns derived from the VSL Rules and Constraints that were developed in collaboration with Project Traffic Engineers. The system is fully automated, but can be overridden by the VSL Operations Engineer. VDOT said that the VSL systems are believed to have a positive impact on alerting drivers to upcoming congestion. These VSLs have been in place since the 1980s, so there is no before/after data on congestion or safety impacts.

The Washington Department of Transportation (WSDOT) has two VSL systems. One system on I-90 is 15 miles long, beginning at MP 46 and ending at MP 61. The other system on US 2 is seven miles long, and beginning at MP 57 and ending at MP 64. This system consists of 15 overhead mounted Flip-disc and LED signs. The speed limit is based on traction requirements, pavement conditions, visibility, weather (precipitation amount and type), and incident types. There are thresholds for the system, and the speed limit is based on a matrix of the conditions given above. Verification by Maintenance Personnel or the Washington State Patrol is required before changing the speed limit on the signs. The only real-time variable that WSDOT takes into consideration when lowering the VSL is the weather on the corridor. The DOT feels that the system is a vital component of the ITS systems employed to keep mountain passes open during the winter storm season.

3.3 Summary

From the survey, it can be concluded that each VSL system operates differently. Each state DOT operates their systems in a way that benefits their state. The urban systems are monitoring incidents and speeds, whereas the majority of the rural systems are monitoring visibility, weather, and pavement conditions.

Each state has different methods of setting thresholds, resulting in the establishment of different types of thresholds. Nine states are using LED signs; one is using VMS; and one is using Static Panel signs. Virginia is the only system that is completely automated. The other ten states require dispatch approval/verification before changing the speeds. Formal evaluations have not been completed on any of the corridors, but each DOT believes that the VSL system is working on their corridors. Table 3-4 summarizes the survey results. N/A signifies systems that are not currently operating or the system was just implemented.

Table 3-4: **Summary of survey results**

State	Corridor	Mile markers	Number of signs	Type of signs	Rural/Urban setting	Real-time variables	Dispatcher Verification/Approval	VSL effective
Alabama	I-10	26 to 35	24	LED	Urban	Weather and vehicle speed	Yes	N/A
Colorado	I-70	EB- 177.4 to 249.4 WB-221.0 to 253.9	15	LED	Rural	Based on chain law	Yes	N/A
Delaware	I-495	From PA state line to Wilmington, DE	23	VMS	Urban	Incidents, weather conditions	Yes	Yes
Florida	I-4	79 to 89	20	LED	Urban	Lane occupancy	Yes	N/A
Maine	I-95 I-295	110 to 191.9 2.8 to 44	70	LED	Rural	Lane occupancy	Yes	Yes
Missouri	I-270	Entire corridor	48	LED	Urban	Road conditions, travel speeds	Yes	N/A
New Jersey	I-95 I-78	62 miles of corridor Entire corridor	109	Static Panels	Urban/Rural	Weather, Downstream incidents (congestion/accidents), Construction	Yes	Yes
Pennsylvania	PA 76 Toll	162 to 172	28	LED	Rural	Visibility	Yes	Yes
Tennessee	I-75	29 to 39	2	LED	Rural	Visibility	Yes	Yes
Virginia	Current Systems I-64 I-664 I-264 Future Systems I-95 I-64	268.3 to 274.1 5.8 to 11.7 5.9 to 7.4 171.93 to 178.56 97.27 to 107.22	6 sets 4 sets 2 sets 13 sets N/A	LED	Urban	Lane occupancy, weather, incidents	No	Yes
Washington	I-90 US 2	46 to 61 57 to 64	15	LED	Rural	Weather	Yes	Yes

Chapter 4 Project Description

The following chapter is a description of the Variable Speed Limit System installed by the Wyoming Department of Transportation including descriptions of: the project location, the weather and crash history along the corridor, the Intelligent Transportation System (ITS) technology on the corridor, and the current interim protocol for adjusting the legal speed limits using the VSL signs.

4.1 Project Location

The I-80 Elk Mountain corridor being analyzed lies between Laramie and Rawlins, Wyoming. Laramie and Rawlins are both in WYDOT District 1, located in the southeast part of Wyoming. Laramie is located in Albany County, and Rawlins is located in Carbon County. The distance between Laramie and Rawlins is approximately 100 miles long and the project corridor is 52 miles long. The project corridor initially began east of Rawlins at the West Elk Mountain Interchange (MP 255.6) and extended to the Quealy Dome Interchange (MP 290.44) approximately 20 miles west of Laramie. During the 2009-2010 winter season the corridor was extended to the west out to the Peterson Interchange (MP 238.15). The entire corridor is a four-lane interstate and a map of the project corridor can be seen in Figure 4-1.

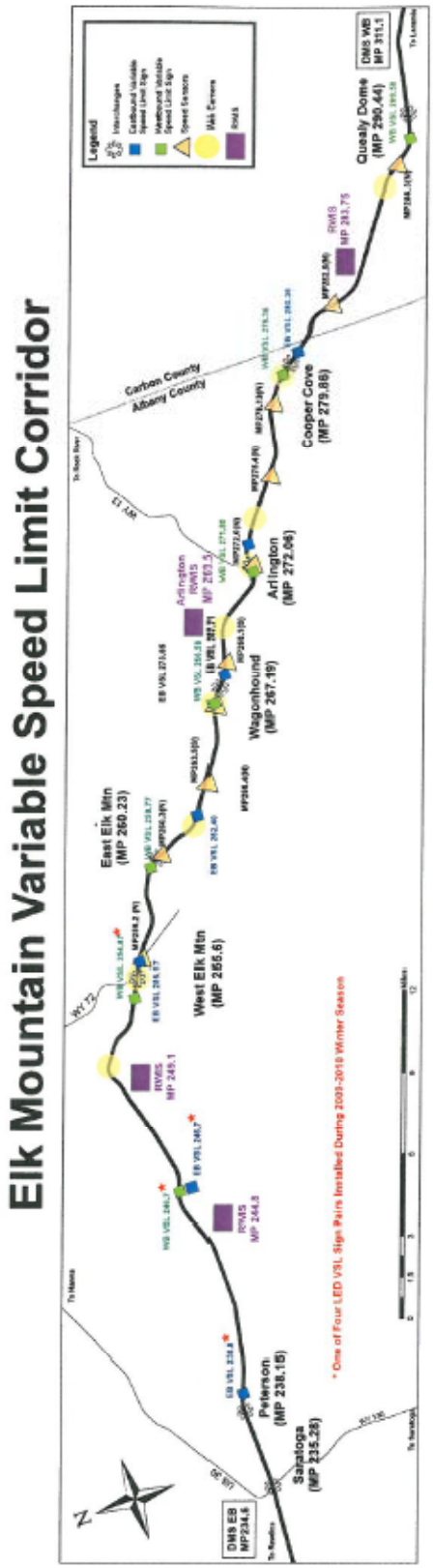

Figure 4-1: Project Corridor Map

According to a study done by the Wyoming Department of Transportation in 2005, the ADT on the corridor is 10,800 vehicles per day. Using vehicle classifications established by the Federal Highway Administration (FHWA), 60% are heavy vehicles, which includes vehicles with three or more axles, 25% are passenger vehicles, 20% are Two-Axle, 4 Tire Single Units, and the remaining percentage is split between motorcycles, buses, and Two-Axle, 6 Tire Single Units (Wyoming Department of Transportation, 2005).

4.2 Crash Analysis

This section takes a closer look at the crash data collected by WYDOT for ten and five year periods. The first period includes all reported crashes from January 1, 2001 through April 15, 2010. The five year period includes reported crashes from February 18, 2004 through February 17, 2009, to correspond with the VSL system beginning on February 17, 2009. The ten year data will help to understand the general pattern of crashes on the Elk Mountain corridor. The ten year time period set can help eliminate statistical discrepancies from one year to another, for example, looking at annual data collected during a year with multiple winter storms versus a year with a very mild winter. The five year data set will consider data that was collected right before VSL system was installed and will be used to set the baseline crash frequencies and crash rates to use in determining the effectiveness of the VSL in reducing crashes on the corridor.

In this section the crashes will be sorted out into three categories: injury, fatal or property damage (PDO) crashes for the ten year and five year time frames: January 1 , 2001 - April 15, 2010 and Feb 18, 2004 - Feb 17, 2009 respectively. The crash numbers

will be compared with the Average Annual Daily Traffic (AADT) data in order to determine the crash rates per million vehicle miles traveled (MVMT).

The last task described in this section considers various crash variables for the five year period before the VSL system was installed, which illustrates the characteristics of the crashes that were occurring. Variables such as weather, lighting, and pavement condition will be analyzed.

Crash Data

Crash data provided by WYDOT shows that, from January 1, 2001 to April 15, 2010, there were 3,389 reported crashes on the I-80 corridor between Laramie and Rawlins, WY from milepost 234 to milepost 311. Approximately 2,600 of those crashes occurred on the VSL corridor between Peterson (MP 238.15) and Quealy Dome (MP 290.44) interchanges.

Figure 4-2 shows a breakdown of crashes for every mile between January 2001 and April 2010. The section with the highest number of crashes was milepost 252 with 86 crashes. There were no segments between MP 238 and 291 that had less than 22 reported crashes during that period. The minimum number of crashes (14) occurred around MP 306, which is outside the VSL corridor.

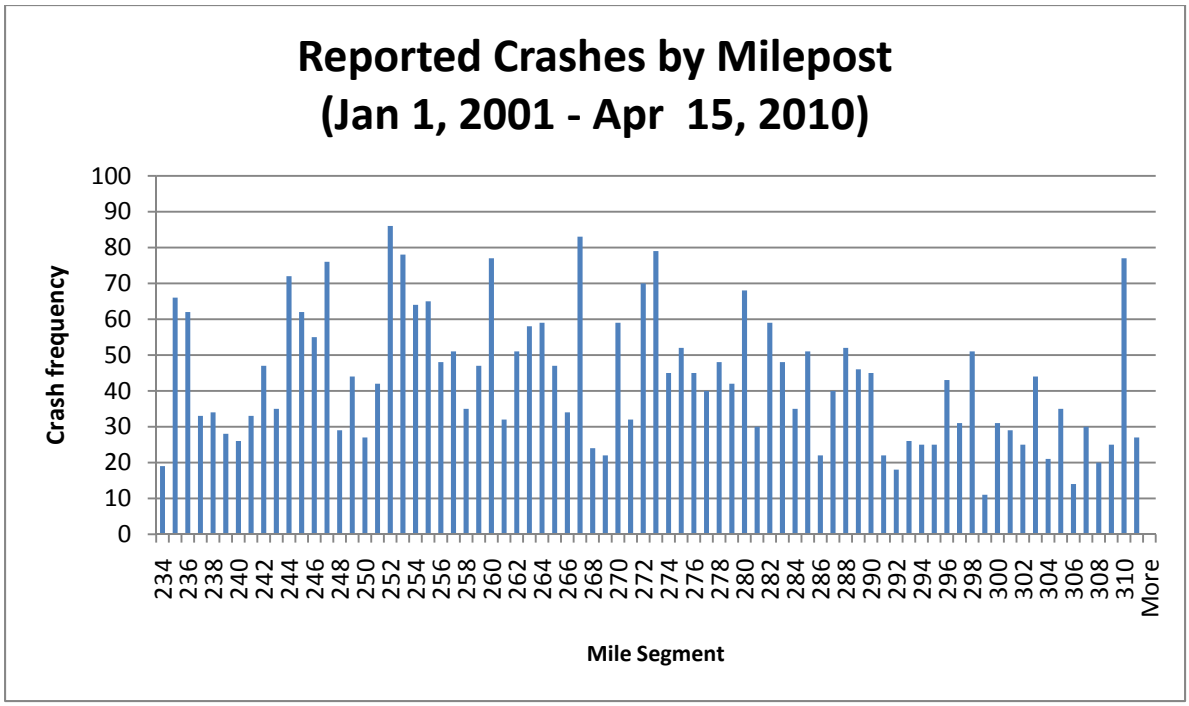

Figure 4-2: Elk Mtn. Corridor 10-Year Crash Frequency (One Mile Segments)

Figure 4-3 shows the crash frequency along the same stretch of road, with the same data aggregated into five mile segments. Milepost 235 for example, includes the crashes that occurred between the 232.50 and 237.49 mileposts. The five mile segment that had the highest amount of crashes was milepost 255 with 306 crashes. Milepost (MP) 245 had the second highest number of crashes with 300 crashes over the 10 year period. It is important to note that there is a west Elk Mtn. interchange located at milepost 255.6. The eastbound (EB) VSL Sign at milepost (MP) 256.2 and westbound (WB) VSL at MP 254.87 were installed in February 2010. There is also a WB VSL sign at MP 246.7 and an EB VSL at MP 246.7. This data shows that there are safety concerns in the corridor between the Peterson (MP 238.15) and Quealy Dome (MP 290.44) interchanges.

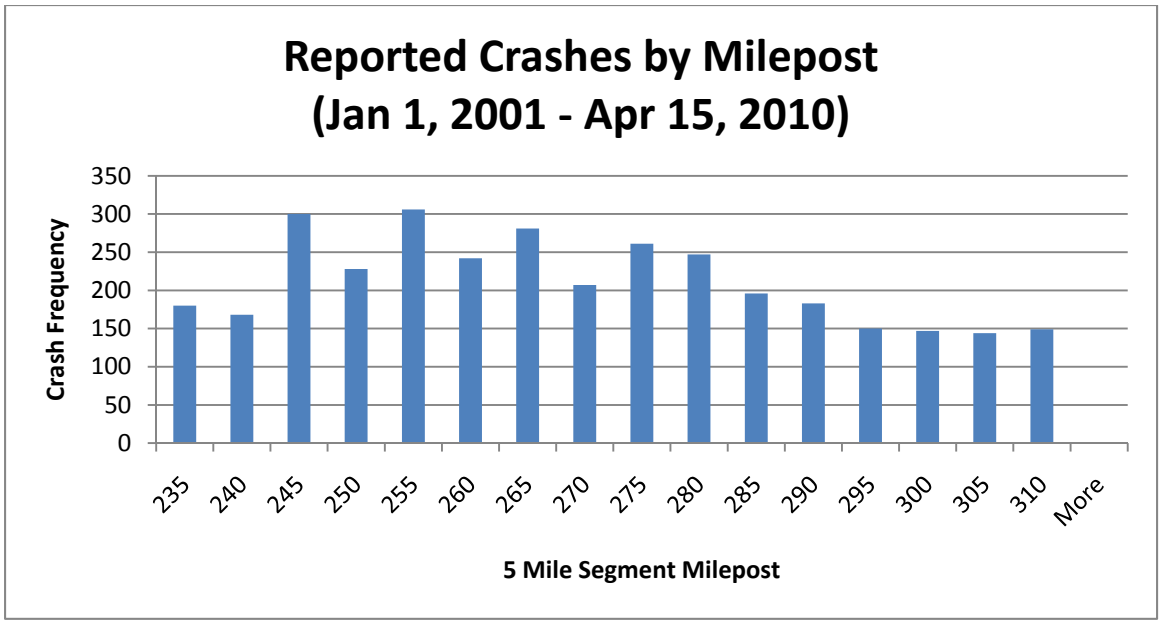

Figure 4-3: Elk Mtn. 10-Year Crash Frequency (Five Mile Segments)

Next, the five year crash dataset was compiled from February 18, 2004 to February 17, 2009, right before VSL signs were installed (Figure 4-4). During this period of time, there were 1,955 crashes along the corridor from milepost 234 to milepost 311. Approximately 1,494 of those crashes occurred on the VSL corridor between Peterson (MP 238.15) and Quealy Dome (MP 290.44). Figure 4-4 shows a breakdown of how many crashes occurred every mile between February 2004 and February 2009. The milepost with the highest number of crashes was milepost 267 with 51 crashes, the second highest was MP 255 with 48 crashes, which was the most troublesome milepost looking back at ten year data. There is an interchange at MP 267.19 (Wagonhound), also a WB VSL sign at MP 266.58 and an EB VSL sign at 267.71 were installed as part of VSL system. There was not a mile segment between Peterson and Quealy Dome that had less than 11 reported crashes during the five year time period from February 2004 to February 2009. Therefore, it can be concluded that there is a persistent crash problem along the corridor.

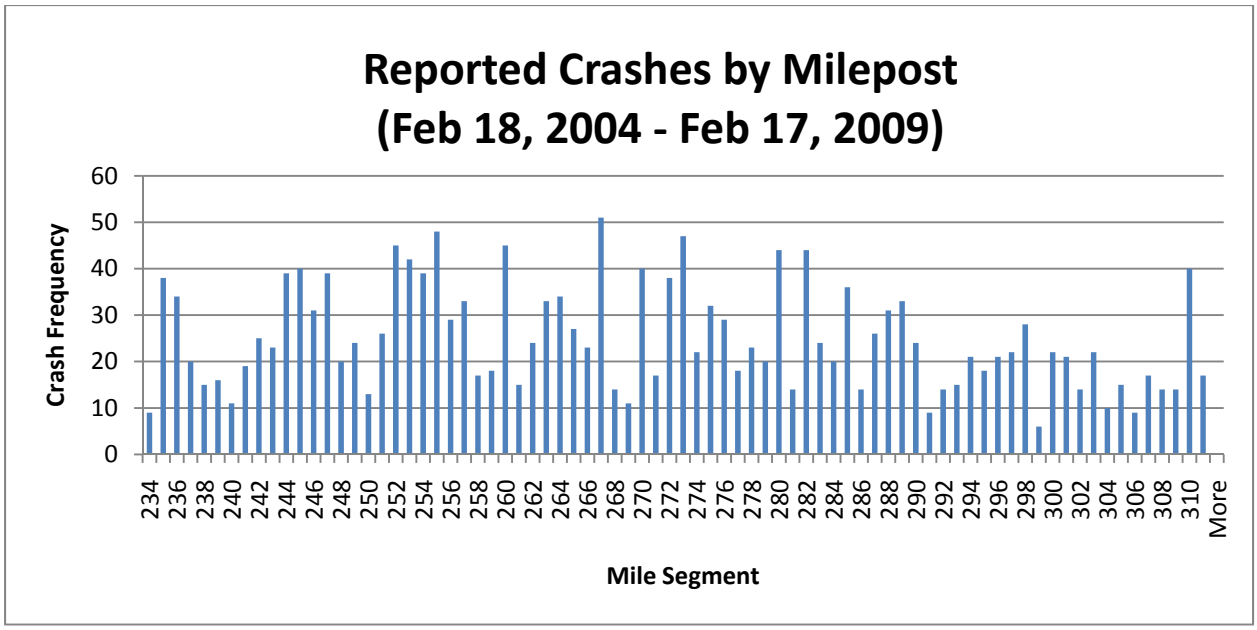

Figure 4-4: Elk Mtn. 5-Year Crash Frequency (One Mile Segments)

Number of Injury and Fatal Crashes

The next step in the crash analysis was to look at crash types the Elk Mountain Corridor Crash Data collected during 10 years by the WYDOT, starting from April 15, 2001 until April 15, 2010 (Table 4-1). The "Total Crashes" column shows the total number of reported crashes, as well as the number of injury and fatal crashes that occurred on Elk Mountain Corridor between mileposts 238 and 291 for each given year. Figure 4-5 shows a graphical representation of the data. The time frame from April 15 to April 14 was selected to allow for the use of crash data from the 2009-2010 winter season, which was the first full winter when the VSL was in use. A crash was categorized by the highest severity occurring with that crash. Meaning a crash that resulted in one or more fatalities counted for one fatal crash.

Table 4-1: Elk Mountain Corridor Crash Data from April 15, 2001 - April 15, 2010

	Total Crashes	Total Injury Crashes	Total Fatal Crashes
April 15, 2001- April 14, 2002	268	72	3
April 15, 2002- April 14, 2003	269	76	6
April 15, 2003- April 14, 2004	252	81	3
April 15, 2004- April 14, 2005	223	62	5
April 15, 2005- April 14, 2006	322	74	3
April 15, 2006- April 14, 2007	302	83	3
April 15, 2007- April 14, 2008	402	91	3
April 15, 2008- April 14, 2009	248	59	0
April 15, 2009- April 14, 2010	181	39	4
Average	274	71	3.3
Total	2467	637	30

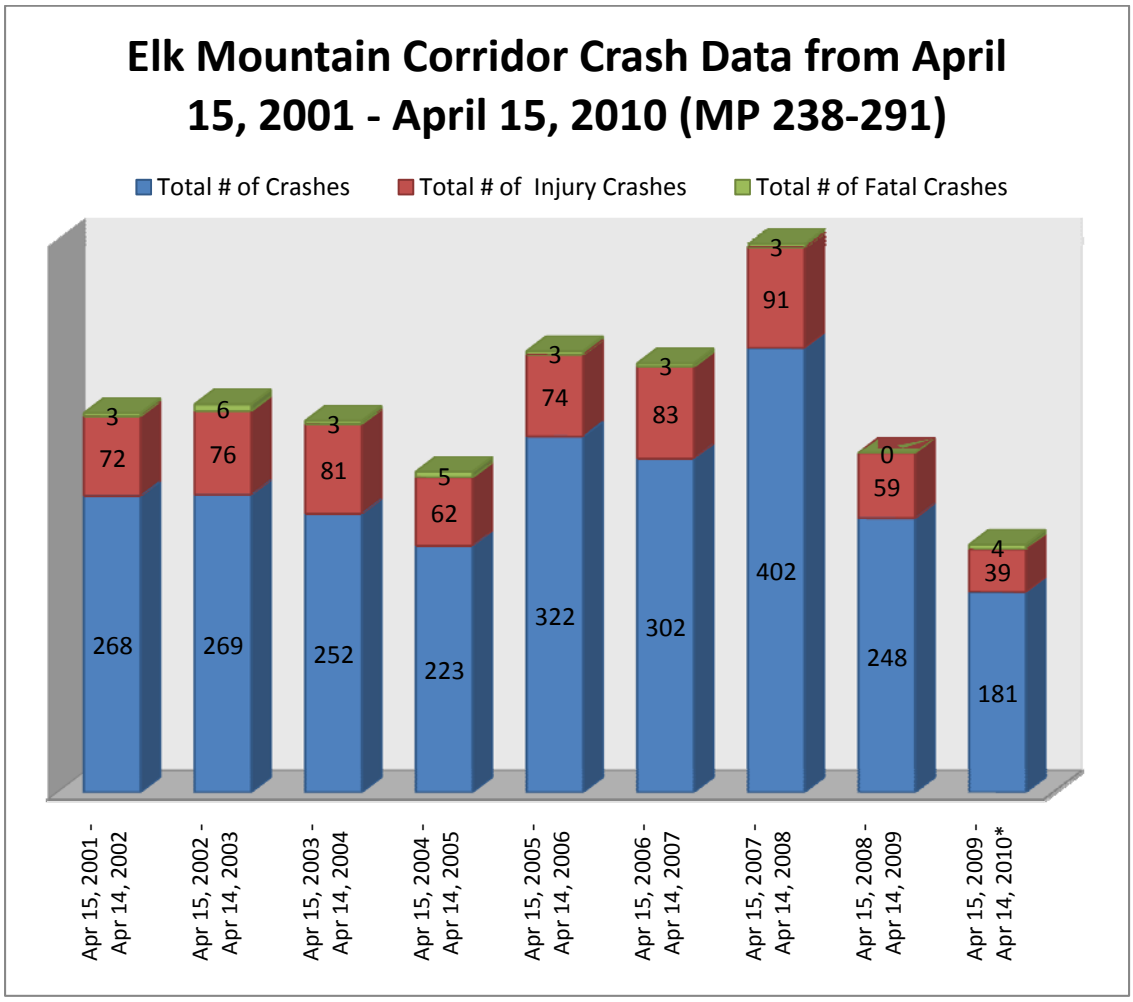

Figure 4-5: Injury and Fatal crashes from 2001 to 2010

From April 15, 2001 through April 15, 2005 the number of crashes stayed relatively constant in the range of 250-270 crashes per year. During the April 2005 – April 2006 period the crash number increased to 322 crashes a year and then increased again in April 2007 – April 2008 to 402 crashes. However, the Annual Average Daily Traffic (AADT) on Elk Mtn. corridor along I-80 also increased to 11,090 in 2007, which is almost a thousand vehicles per day higher compared to previous years in this decade (Table 4-2). It is reasonable to assume that increase in daily traffic will result in higher numbers of crashes as an outcome. Likely due to the recession people travel less and freight volumes are reduced, so for the first time AADT numbers went down in 2008 and the trend continued the following year in 2009. In 2009 there were 900 fewer vehicles on the Elk Mtn. corridor compared to two years prior, in 2007.

Table 4-2: Average Annual Daily Traffic on Elk Mountain Corridor (MP 299.3)

Year	AADT
2009	10,194
2008	10,306
2007	11,090
2006	10,870
2005	10,860
2004	10,760
2003	10,450
2002	10,590
2001	10,120
2000	10,100

*Source (WYDOT Automatic Traffic Records Report, 2009)

The number of crashes that resulted in at least one fatality has been consistent over the time period from April 2001 to April 2005 and in last five years has remained in one and two percent range. In terms of the number of crashes that involved at least one or more injuries, almost one third of all crashes were defined as injury crashes. Again, injury crashes like fatal crashes don't account for the number of injuries or fatalities but

rather for the portion of all crashes that had at least one person injured or killed as a result of it. During the period of April 15, 2009 - April 15, 2010 almost 21.5 percent of crashes were injury crashes.

In order to set the baseline crash rate for the corridor the crash data from the last five years taking February 17, 2004 to February 18, 2010 was considered (see Table 4-3 and Figure 4-6). Since the VSL was introduced in mid February of 2009, a slightly different time line has been chosen for this analysis. The number of total crashes increased between February 2007 and February 2008 to 353 crashes (87 injury and 4 fatal crashes included) and has decreased since then. The lowest number of injuries and fatal crashes appeared last year between February 2009 and February 2010. Only 197 crashed occurred during that time frame and 38 injury and 3 fatal crashes. The number for fatal crashes is consistent with the five year average number of 3 fatal crashes for a whole period. The average numbers for the six year period were 282 crashes and 70 injury crashes.

It is too early to make final conclusions about whether the VSL system is improving safety on the Elk Mountain corridor on I-80 due to the nature of safety data. As mentioned before there are other baseline factors to consider, such as exceptionally harsh winter conditions and an overall decrease in number of vehicles on the road.

Table 4-3: Elk Mountain Corridor Crash Data from Feb 18, 2004 - Feb 17, 2010

	Total Crashes	Total Injury Crashes	Total Fatal Crashes
Feb 18, 2004- Feb 17, 2005	237	67	6
Feb 18, 2005- Feb 17, 2006	292	72	2
Feb 18, 2006- Feb 17, 2007	329	87	4
Feb 18, 2007- Feb 17, 2008	353	84	2
Feb 18, 2008- Feb 17, 2009	284	72	1
Feb 18, 2009- Feb 17, 2010	197	38	3

Average	282	70	3
Total	1692	420	18

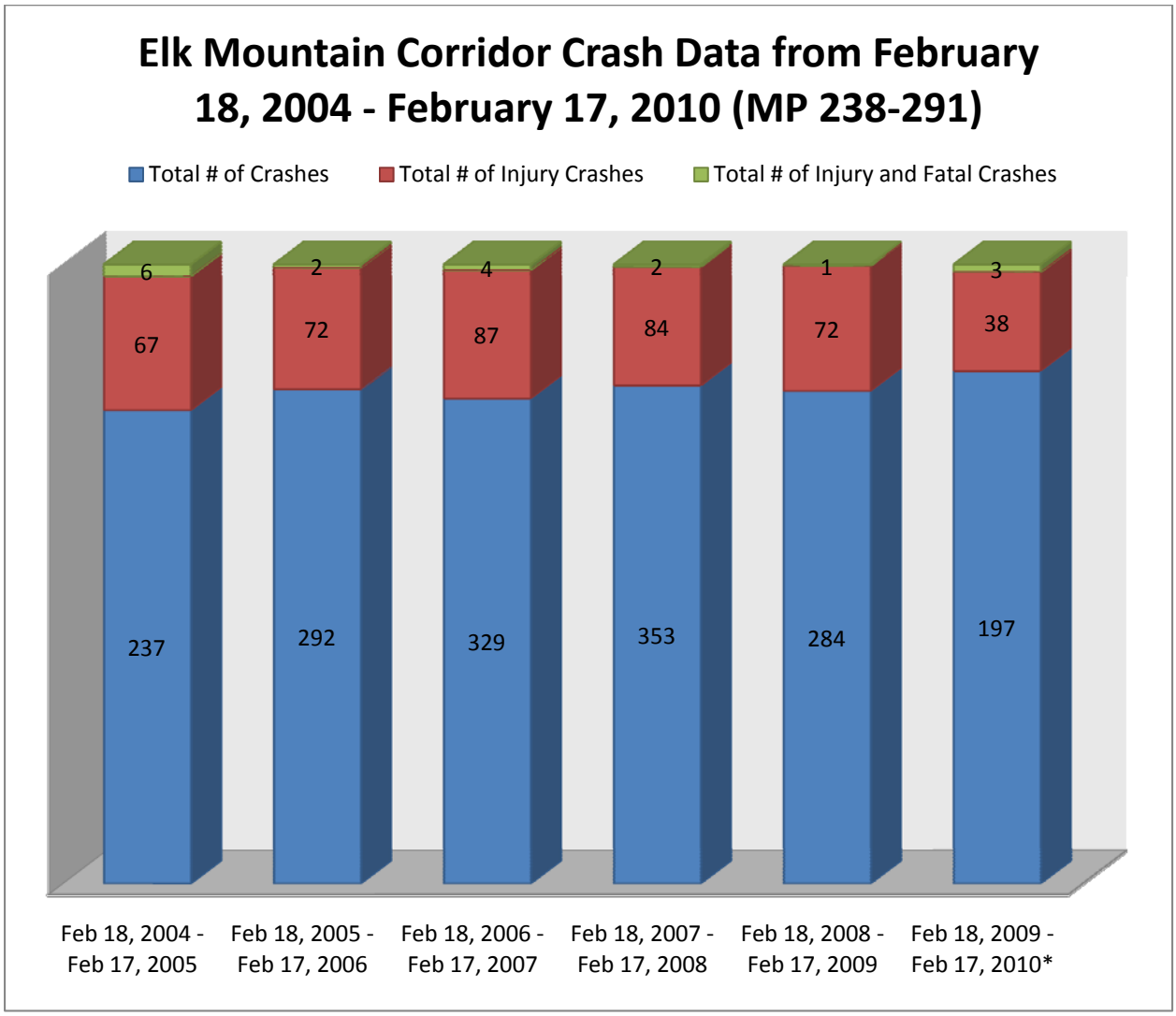

Figure 4-6: Injury and Fatal crashes from 2004 to 2010

Crash Rate

The WYDOT Safety Office manages a crash records database which contains a record of all reported crashes. A five year crash report was provided for further crash rate analysis; it spanned from February 18, 2004 to February 17, 2010. The length of the VSL Corridor considered was between MP 238 and MP 291.

Crash rate information is a measure of the safety of a particular roadway section. To determine crash rates, a number of important facts about a roadway need to be known, including the AADT, the length of the roadway section, and the number of crashes that have occurred on that section. Crash rates are normally expressed as the number of crashes per million or hundred million Vehicle Miles Traveled (VMT). Crash rates can be calculated using Equation 1 and Equation 2.

$$\boldsymbol{VMT = AADT * Length\ of\ corridor * 365} \quad \textbf{Equation 1}$$

$$\boldsymbol{Crash\ Rate = \frac{\#\ of\ crashes * 1{,}000{,}000}{VMT}} \quad \textbf{Equation 2}$$

Crash rates, the number of crashes per million vehicle miles traveled (MVMT) were calculated for the five year time period in Table 4-4. The average crash rate over the Elk Mountain corridor from MP 238 to 291 was 1.433 crashes per million VMT for the period between February 2004 and 2009 before the VSL system was initially implemented. For the same period the average injury and fatal crash rate was 0.381 and fatal crash rate was 0.014.

Table 4-4: Elk Mountain VSL Corridor Crash Rates (Feb 2004 - Feb 2010)

		Total Crash Rate	**Total Injury & Fatal Crash Rate**	**Total Fatal Crash Rate**
Yr 1 Before	Feb 18, 2004- Feb 17, 2005	1.139	0.351	0.029
Yr 2 Before	Feb 18, 2005- Feb 17, 2006	1.390	0.352	0.010
Yr 3 Before	Feb 18, 2006- Feb 17, 2007	1.565	0.433	0.019
Yr 4 Before	Feb 18, 2007- Feb 17, 2008	1.645	0.401	0.009
Yr 5 Before	Feb 18, 2008- Feb 17, 2009	1.424	0.366	0.005
	Average Crash Rate (2004-2009)	**1.433**	**0.381**	**0.014**
Yr 1 After	Feb 18, 2009- Feb 17, 2010	0.999	0.208	0.015

The maximum crash rate was 1.645 crashes per million VMT between February 2007 and February 2008. An injury and fatal crash rate of 0.433 crashes per MVMT was

the highest between February 2006 and February 2007. The highest fatal crash rate was 0.029 crashes per MVMT between February 2004 and February 2005. The minimum crash rate was 0.999 crashes per million VMT, between February 2009 and February 2010, which was right after the VSL system was put in place. These results are shown in Figure 4-7: Elk Mtn. Crash Rate 2004 to 2010.

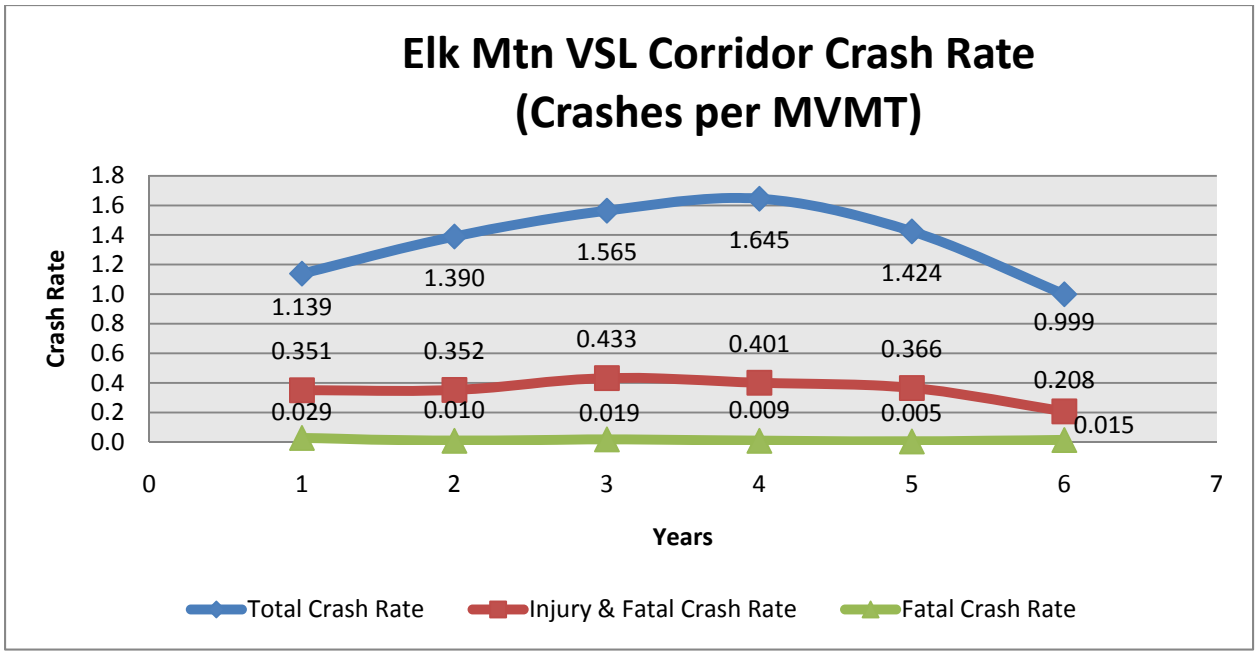

Figure 4-7: Elk Mtn. Crash Rate 2004 to 2010

Ever since daily traffic declined in 2008, total crash rate and injury & fatal rate have gone down to 0.999 and 0.208 crashes per MVMT respectively. Since the crash rate takes into account the AADT, it means that a less congested roadway is not the only factor in increasing safety on the Elk Mountain Corridor.

At least two more years of data is necessary before statistical conclusions can be drawn about the effectiveness of the VSL system on reducing crashes. It is expected that if the AADT rates go up in the next few years the total number of crashes will increase as well. It is harder to predict however, how the injury & fatal crash and fatal crash rates

will change. It is possible that the VSL system will change the types of crashes that occur on the corridor as well as the overall crash numbers. The following section looks at various crash variables for the five year period before the VSL system was installed to illustrate the characteristics of the crashes that are occurring.

Crash Variables Analysis

There were 1,955 crashes between February 18, 2004 and February 17, 2009 between MP 238 and 291, before VSL system came into the effect. When the WYDOT reports for this period were analyzed, some of the most significant baseline conditions turned out to be a human factor, lighting, weather, and road conditions.

When looking at the crashes on Elk Mountain Corridor it becomes clear that the majority of accidents are one vehicle crashes; meaning only one vehicle is involved in the incident (Figure 4-8). Only 24 percent of crashes were crashes when two moving vehicles collided with each other. The other 76 percent of crashes were due to most likely a human error.

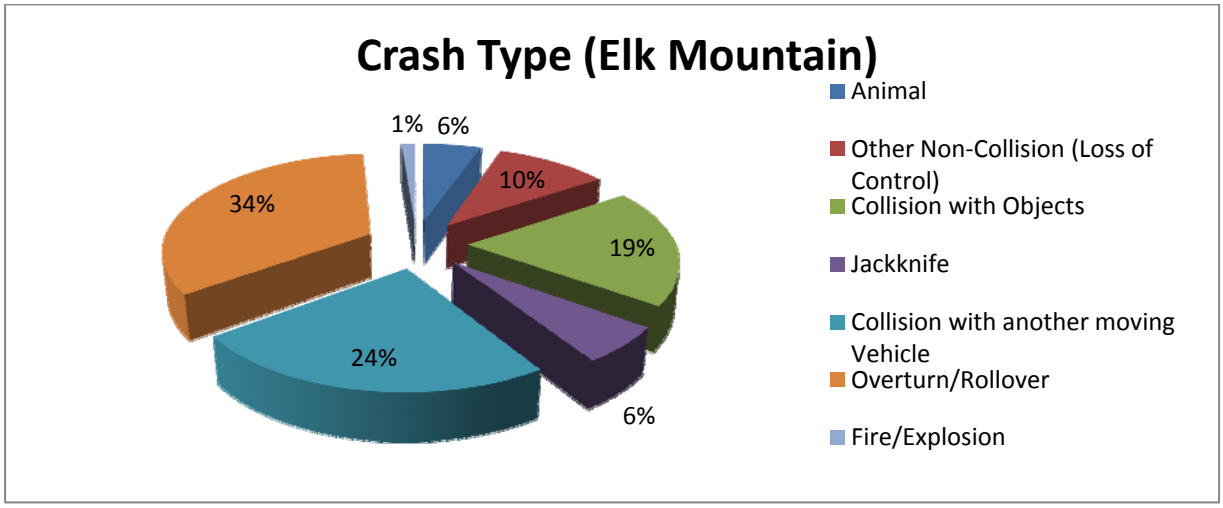

Figure 4-8: Elk Mtn. Crash Type 2004 to 2009

Nineteen percent of all crashes resulted in a vehicle colliding with and fixed object such as a barricade, bridge structure, cut slope, delineator post, earth or snow embankment, fence, parked vehicles, utility pole or trees. Another 34 percent of vehicles overturned or rolled over and 6 percent Jackknifed. In 10 percent of cases drivers lost control of the vehicle, which resulted in a crash. Another interesting fact is that in spite of the wildlife abundance on I-80, crashes which involved collision with an animal account only for 6 percent of all accidents.

Lighting condition doesn't seem to be a major factor for crash occurrence. The majority (64 percent) of crashes happened during daylight and only 30 percent on dark unlighted part of the interstate I-80 (Figure 4-9). A small percent of crashes recorded happened at dawn or dusk, both account for only 2 percent.

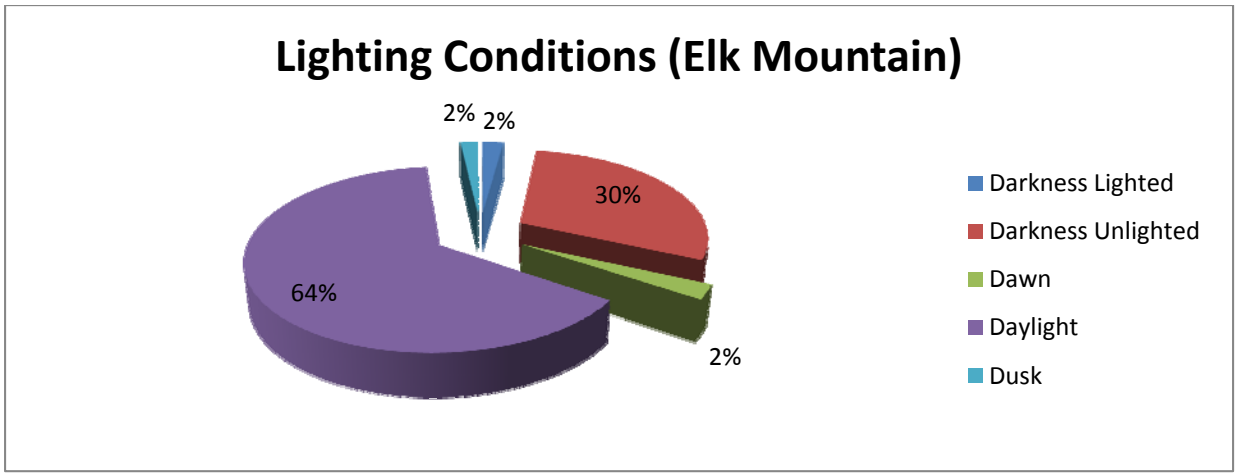

Figure 4-9: Elk Mtn. lighting condition at the time of crash (2004- 2009)

Weather conditions give a better picture in an attempt to characterize the crashes taking place along the corridor. As shown on Figure 4-10, less than one third (27 percent) of the crashes occurred during "ideal" weather conditions, when the sky was clear and pavement was dry. Twenty-nine percent of incidents occurred when it was snowing and

another 6 percent during blowing snow conditions. In 14 percent of the crashes drivers experienced severe wind conditions. Snow and wind conditions significantly decrease visibility for drivers. These conditions make control of the vehicle harder especially for the drivers with little experience operating a vehicle during high wind. Another 14 percent of crashes occurred during clear weather conditions but on icy, frosty or wet pavement. This means that the road condition is also a very important variable.

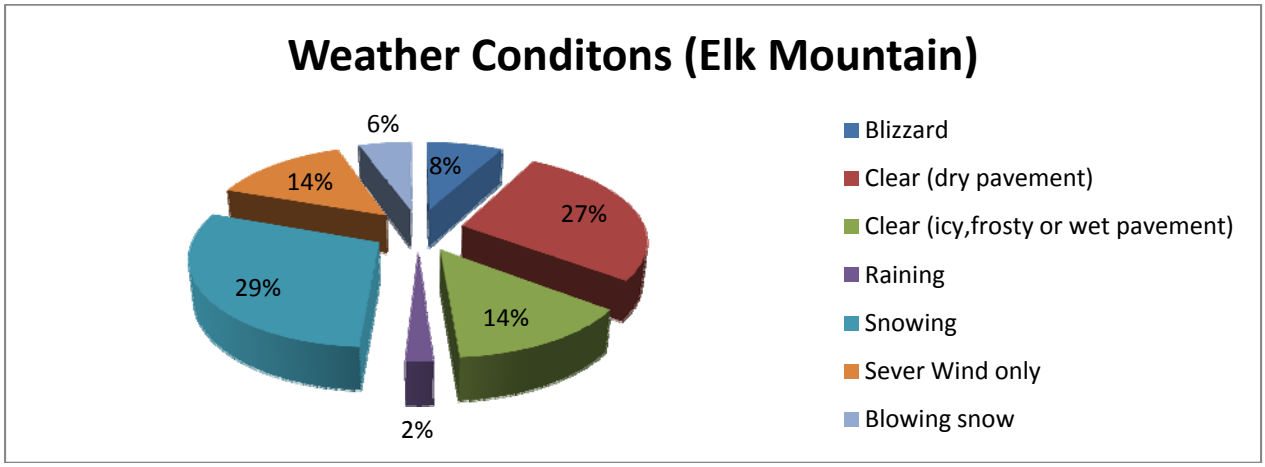

Figure 4-10: Elk Mtn. weather condition at the time of crash (2004- 2009)

Figure 4-11 shows the road condition at the time of accidents. The state of the road is a significant factor, because with a relatively high speed limit of 75 mph on I-80 in WY, it is very easy to lose control of the vehicle in a scenario when the pavement is slick or wet. It is also harder for a driver to determine when the traction between the tires and pavement has been reduced, since icy spots are not obvious and can be covered by patches of drifted snow. Therefore it is critical to determine whether this condition exists and inform drivers about it whether through dynamic messages or reducing the speed by using the VSL system. In the majority of incidents (51 percent) the road was icy or frosty. In 7 percent of cases there was snow on the road and in 4 percent the pavement was wet.

The road was dry and didn't contribute to the cause of the incident in only 36 percent of crashes.

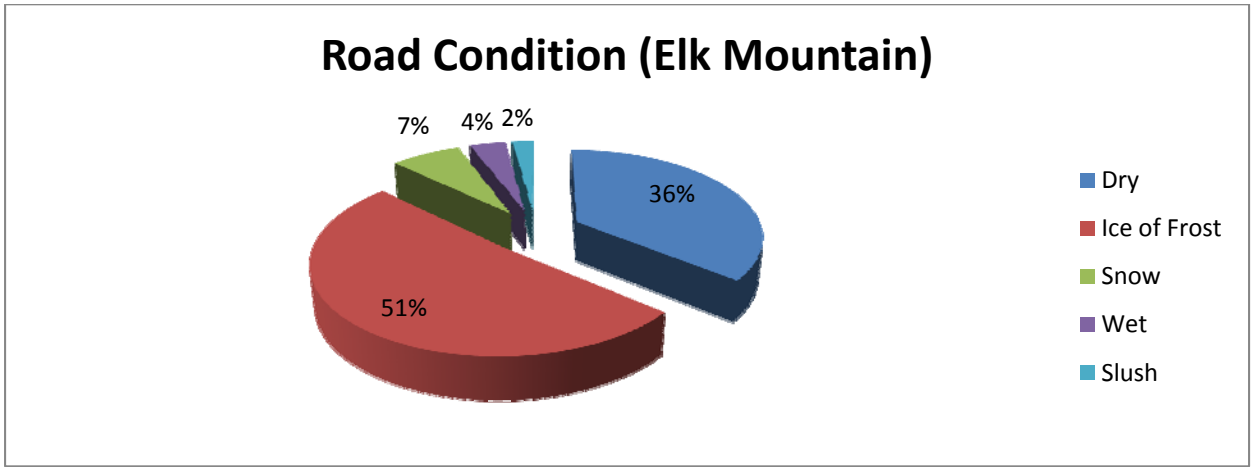

Figure 4-11: Elk Mtn. road condition at the time of crash (2004- 2009)

The final graph, Figure 4-12, breaks down the crashes into the ones that had at least one injury incident or fatal incident and the ones that resulted in only damage to the vehicle. It is clear the majority of crashes (72 percent) resulted in only property damage. Crashes that caused at least one injury accounted for 27 percent of all crashes and only one percent of all crashes had at least one fatality. Even though the percent of fatal crashes is extremely low, it is worth noting that in many of those fatal crashes more than one person was killed and several others injured. For example, a crash that occurred on March 29, 2006 on MP 269.88 involved 22 vehicles, 45 people, and resulted in 6 deaths and 12 injuries. The crash happened during snowing conditions and on icy/frosty pavement.

Other variables have been considered such as road alignment and grade, but were found to be insignificant, since very few crashes happened on a steep grade or on a curvy part of the road.

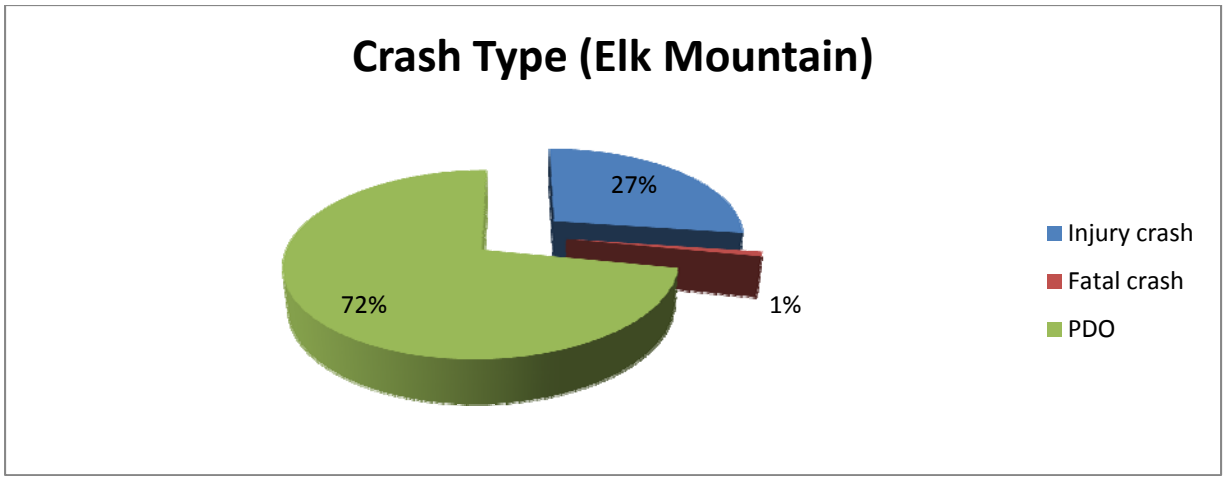

Figure 4-12: Elk Mtn. Road condition at the time of crash (2004- 2009)

Crash data is a very important tool in understanding why crashes happen and what parts of the interstate can be considered as hot spots. It also helps in determining the type of the accidents and some variable factors that precede those incidents. During the analysis it became clear, that the corridor between Peterson (MP 238.15) and Quealy Dome (MP 290.44) is prone to high crash rates.

4.3 Road Closures

The I-80 Elk Mountain corridor is known for poor weather conditions. Average wind speeds can reach up to 75 mph, and wind gust speeds can reach up to 90 mph. Average wind speed is the average wind velocity measured in miles per hour at the Road Weather Information System (RWIS) station. Wind gust speed is the maximum wind speed that is measured at the RWIS station during a certain period. Wind speeds this high can cause heavy vehicles to overturn or create problems for travelers, particularly for those who have never traveled in high wind conditions. Other problematic weather conditions include snow, ice, limited visibility, and blowing snow.

The conditions mentioned in the previous paragraph are often the reasons that the corridor must be closed. WYDOT is able to close one direction at a time or close both directions if an event arises or conditions warrant. A road closure database is maintained by the WYDOT Traffic Management Center (TMC) in Cheyenne. The TMC records the date and time that the road is closed, the direction in which the road was closed, the mileposts that are affected by the closure, the reason it was closed, the date and time of the road opening, and any other notes pertaining to the closure. From May 1998 through April of 2010, the corridor was closed a total of 176 times with an average duration of 8 hours and 32 minutes for the closures. Table 4-5 summarizes the number of closure, average closure durations, and the cumulative closure times for each twelve month period. Note that the last period from May 2009 through April 2010 was the first full year that the VSL system was operational.

Table 4-5: Elk Mountain Corridor Road Closure Frequency and Duration

	Total # of Closures	**Average Closure Time**	**Cumulative Closure Time**
May '98 - April '99	5	6:50	34:13
May '99 - April '00	6	4:14	25:27
May '00 - April '01	10	9:17	92:59
May '01 - April '02	7	13:36	95:18
May '02 - April '03	14	13:08	183:56
May '03 - April '04	7	3:42	25:54
May '04 - April '05	13	4:25	57:33
May '05 - April '06	14	6:38	92:55
May '06 - April '07	17	7:51	133:41
May '07 - April '08	51	10:18	526:06
May '08 - April '09	20	6:37	132:34
May '09 - April '10	12	8:29	101:49
Total May '98-April '10	**176**	**8:32**	**1502:25**

Figure 4-13 shows the number of closures per year and the yearly average duration of closures for the twelve year period that data are available.

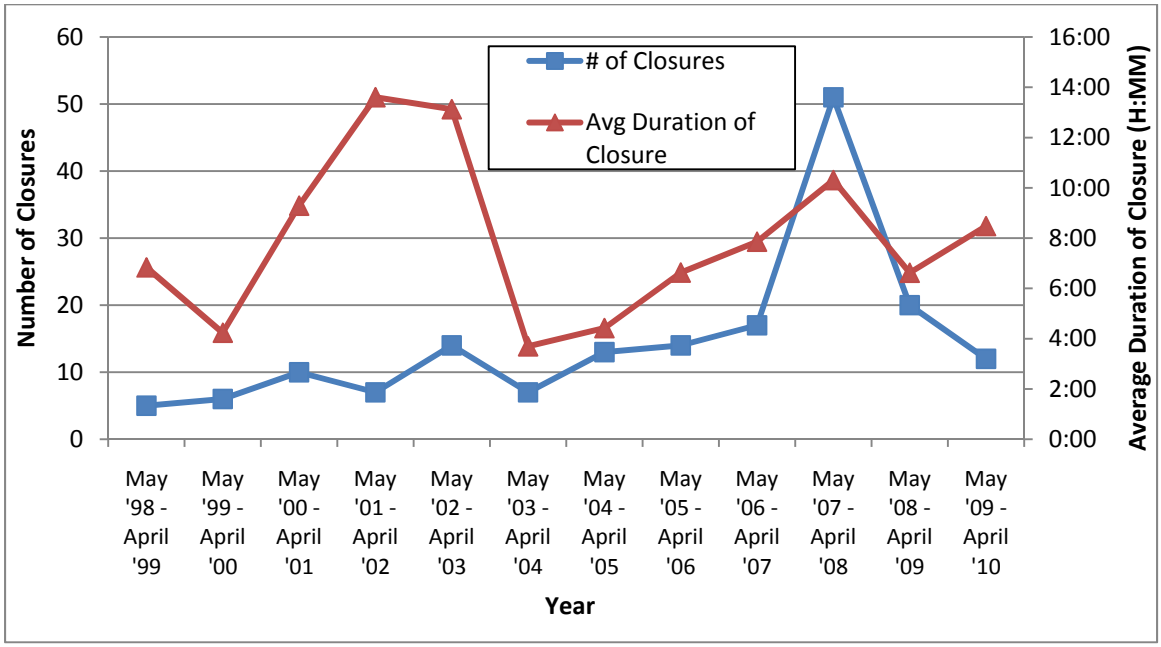

Figure 4-13: Corridor closures broken down by direction

The road can be closed because of weather conditions, an accident, both weather and an accident, or if a closure in a different corridor causes traffic to back up in a city According to the road closure data for the period from September 2007 through May 2008, accidents were almost always the reason that a single direction of the road was shut down. As it can be seen in Figure 4-14, weather is the reason the corridor was closed sixteen out of the twenty-nine times. Variable Speed Limits can help reduce the speed on the corridor so that, even though weather along the corridor is deteriorating, the road can remain open and drivers can travel at speeds that are safe for the conditions.

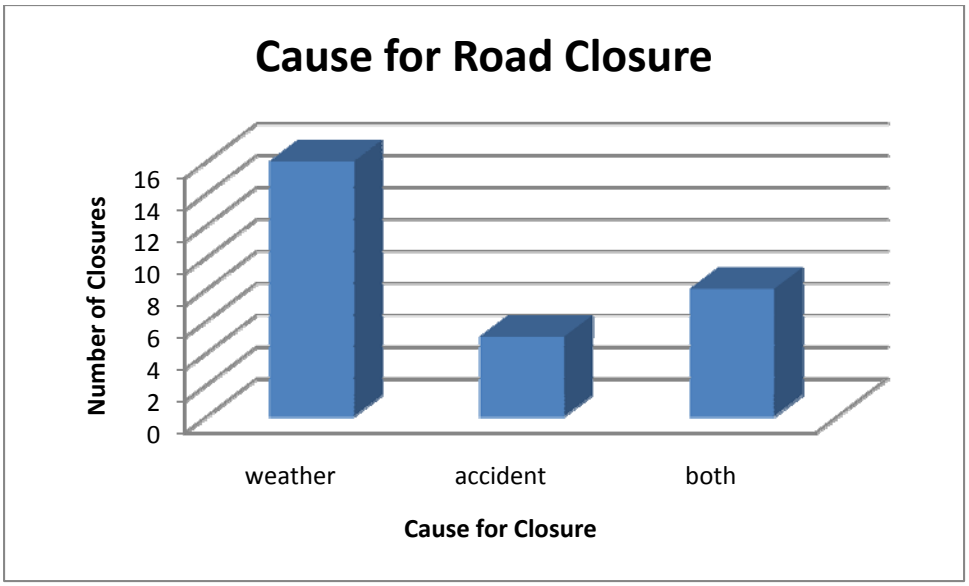

Figure 4-14: Reason for road closure

An 8-hour closure results conservatively in an estimated cumulative impact of almost $8 to $12 million in delay costs (Young & Liesman, 2007). Because costs are so high to close the interstate, the duration of each closure was considered. The maximum duration of a closure on the corridor from September 2007 to May 2008 was 22 hours and 54 minutes. The closure impacted both directions and occurred because of multiple accidents. The average closure on the corridor was 8 hours and 24 minutes. Variable Speed Limits are able to keep drivers traveling at speeds that are safe for conditions, which should allow the road to remain open. Even though vehicles are traveling at reduced speeds, the road is still open and the economy is not losing as much money due to freight being delayed.

One of the goals of the VSL system is to reduce the frequency and duration of the road closures on the Elk Mountain Corridor. Due to year to year variations in weather severity it will take several winters with the VSL system implemented before any

conclusions can be made about the system's effectiveness in meeting this goal. The data described in this section will serve as a baseline to compare against future years.

4.4 ITS Technology

The ITS technology along this corridor is continually expanding. This section will discuss the technology that existed along the corridor before the project began, the technology that was implemented at the beginning of the VSL project, and technology that was implemented after the VSL was installed.

Existing Technology

The existing ITS components available for drivers on I-80 between Laramie and Rawlins are one RWIS and two Dynamic Message Signs (DMSs) that are located at either end of the corridor (MP 234.6 and 311.1).

The DMS at MP 311.1 provides information to drivers leaving Laramie and traveling westbound towards Rawlins. The DMS at MP 234.6 is located at Walcott Junction, to provide information to drivers traveling eastbound towards Laramie.

The RWIS station is located at the Arlington Interchange (MP 272.0). The station collects information such as temperature, dew point, and wind speed information. A picture of the RWIS station can be seen in Figure 4-15.

Figure 4-15: RWIS station at MP 272.0

Drivers who are looking for pre-trip information about the corridor can utilize the www.wyoroad.info website. The website features condition information, condition maps, construction information, and supplemental information. Drivers can acquire information about the conditions along the corridor, such as whether the road surface is wet or dry and if there is blowing snow. The condition section also contains information about closures and advisories. Condition maps provide the observed radar, temperature, and weather information for the entire state. Drivers can use these maps to see what type of weather could be coming towards the corridor they plan to drive. A list of the construction projects in the state is provided to indicate locations where a driver may run into construction delays. The supplemental information includes images from web cameras located at the Arlington (MP 272.0) and Walcott Junction Interchange

(MP 235.23), giving drivers a view of the road at those locations. Each camera shows images of the road heading in the East direction, the West direction, and a view of the roadway surface. A picture of the web camera at the Arlington Interchange is shown in Figure 4-16. A picture of what drivers can see on the internet is shown in Figure 4-17. Atmospheric sensors provide the driver with information about the average wind speed, wind gust speed, wind direction, and air temperature.

Figure 4-16: Web Camera at Arlington Interchange

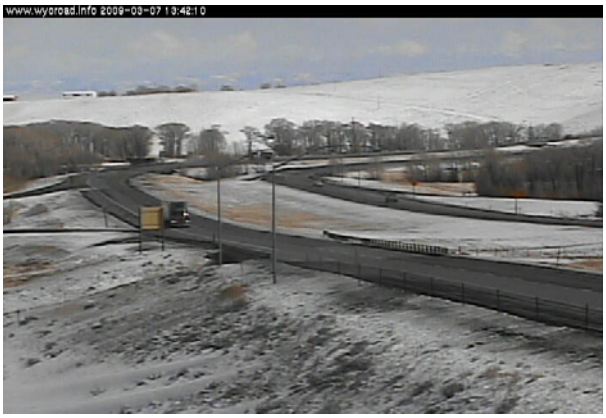

Figure 4-17: Web camera image facing East at Arlington Interchange

Drivers can also access WYDOT's 511 Travel Information from their phone. Drivers are able to choose their travel route. After selecting the desired route, they can hear the condition report for their direction of travel, for a portion of the route or for the entire route. The recording provides weather forecasts, including predicted changes in temperature, wind speed and direction, and visibility for the next six hours. The travel information provided by 511 also includes road surface conditions, closure and advisory information and current weather conditions.

Installed Technology with VSL Implementation

Ten speed sensors have been placed along the corridor as part of this research project. The speed sensors are Wavetronix SmartSensorHD. The speed sensors use a Dual Radar design that sends out two radar beams along the road. The speed sensors can measure traffic volume, individual vehicle speed, average speed, 85th percentile speed, average headway and gap, lane occupancy, and vehicle classification. This type of detection determines vehicle speed by measuring the delay from one radar beam to the next and can also determine length-based vehicle classification. Based on the length of the vehicle, the speed sensor determines the classification of the vehicle into one of eight vehicle categories (Advanced Traffic Products, 2009).

The speed sensors were installed to correspond with the proposed VSL signs locations. Because of the location, some of the speed sensors were not initially able to transmit data to the central database at WYDOT. Initially four sensors did not have communications while six speed sensors did. Table 4-6: Speed sensor description gives a description of the speed sensor, including the type of communications for each sensor. The directional description denotes the side of the road on which that the sensor has been

installed. The sensor measures speed across all four lanes of highway, but the lane descriptions used by the sensor (lane 1, lane 2, etc) are dependent on which lane is closest to the sensor. A picture of one of the speed sensors can be seen in Figure 4-18. By the 2009-2010 winter season all of the speed sensors were able to communicate and transmit data to the TMC.

Table 4-6: Speed sensor description

Speed Senor (MP)	Directional location	Type of communications
256.2	WB	WYDOT
260.3	WB	WYDOT
263.5	EB	WYDOT
266.4	WB	WYDOT
268.1	EB	Manually downloaded
272.5 (273.1)	WB	Manually downloaded
275.4	WB	WYDOT
278.13	WB	Manually downloaded
282.5	WB	Manually downloaded
288.3	WB	WYDOT

Figure 4-18: Picture of Speed Sensor at MP 282.5

WYDOT implemented a seasonal speed limit on October 15, 2008 that reduced the speed limit from 75 mph to 65 mph during the winter months. Because of the seasonal speed limit, WYDOT installed static signs that are also being used as part of the VSL system.

Two signs located at either end of the Elk Mountain corridor inform drivers that "SEASONAL SPEED LIMIT STRICTLY ENFORCED". Along the corridor, there are seven interchanges. Each entrance ramp also has a sign that informs drivers that "SEASONAL SPEED LIMIT IN EFFECT". These signs are hinged and are only displayed between October 15th and April 15th.

Since conditions on the corridor are unpredictable, four split-message signs on the corridor warn drivers that they could encounter hazardous conditions. The top half of the sign says "HAZARDOUS CONDITIONS MAY EXIST" and the bottom half says "SPEED LIMIT STRICTLY ENFORCED". These signs are not hinged and are displayed year round.

Twenty VSL signs in ten locations were installed along the corridor in February 2009. Each sign is a scrolling-film panel sign. This means that the speed limits are pre-printed on a film that sits inside the speed limit sign. When the speed limit is changed, the film scrolls through to the selected posted speed. The speed limits that are printed on the film are 75, 65, 60, 55, 50, 45, 40, and 35.

Since such a large percentage of the vehicles are heavy vehicles, VSL signs were installed in pairs. At each VSL location, there is a sign located on the shoulder and on the median. This is so that drivers can see the speed limit signs no matter which lane they are traveling in and what type of vehicle they are traveling behind. When the speed

limit on one sign is changed, the other sign displays the same speed limit. A picture of the VSL signs can be seen in Figure 4-19. Each sign has a flashing beacon that is activated when the speed limit is reduced, and when the speed limit is reduced, "REDUCED", placed on a bright yellow background, appears at the top of the VSL sign.

Figure 4-19: VSL sign (scrolling film)

Portable DMSs

Four Portable Dynamic Message Signs (DMSs) are located along the corridor. The DMSs are used to inform drivers that they will experience reduced speed ahead. When WYDOT puts a message on the DMS, it is recorded in the DMS log.

Table 4-7: Location of the Portable DMSs gives the locations of the portable DMSs. There are three signs in the westbound direction and one in the eastbound direction.

Table 4-7: Location of the Portable DMSs

Milepost location of Portable DMS	Direction
255.4	WB
265.5	EB
268.0	WB
280.0	WB

Speed Radar Signs

Speed radar signs are placed near the cities on either end of the corridor, but they do not have fixed locations. The purpose of the speed radar signs is to show the drivers the speed at which they are driving.

Technology Installed After VSL Implementation

The technology on this corridor is still evolving. WYDOT is currently in the process of installing additional RWIS along the corridor. Additional RWIS stations will be beneficial because the surface and atmospheric conditions will be known in more than one location. New RWIS were installed at the following mileposts:

- 244.8,
- 249.1, and
- 283.75,
- 297.66.

Along with more RWIS stations, WYDOT has installed more cameras along the corridor. The additional cameras allow the TMC to see actual the conditions along the corridor and aid drivers who are looking for pre-trip information on conditions. New cameras were installed at the following mileposts:

- 252.16,
- 255.6,
- 262,
- 266.58,
- 269.5, and
- 272.06,
- 273.85,
- 279.36,
- 287.5,
- 297.66.

During the 2009-2010 winter season, eight additional VSL signs were installed at four locations (238.8 EB, 246.7 EB, 246.7 WB, 254.87 WB) to extend the VSL corridor. The eight new VSL signs used LED display technology instead of scrolling film technology. Figure 4-20 is a picture of a new VSL with LED display technology.

Figure 4-20: VSL sign (LED)

4.5 Current Protocol

The following section describes the policy that was established for the initial implementation of the VSL system. This protocol was implemented on February 13, 2009. The Wyoming Highway Patrol (WHP) troopers, maintenance foremen, and the Traffic Management Center (TMC) may reduce the speed limit based on the rules set forth in the following VSL policy.

Wyoming Highway Patrol

The WHP may initiate a reduction in the legal speed based on visual inspection of the conditions. If conditions warrant a speed limit reduction, the following process must be followed.

1. The trooper will change his radio to the DOT1 channel and request assistance from the TMC.
2. The trooper must identify him/herself by badge number.
3. The trooper then identifies the area in which the conditions are poor and asks the TMC to tell them the current pace speed on that section of roadway. For example "Interstate 80 in the westbound direction from MP 260.23 to MP 255.6". The pace speed is defined in the WYDOT policy as the average speed plus five miles per hour.
4. The TMC Operator will reference the real-time speed sensor data and provide the trooper with the pace speed.
5. The trooper will indicate the location of the corridor and the speed adjustment they recommend based on the pace speed and their personal observation of the weather and roadway conditions.
6. The TMC operator will repeat the request to the trooper to ensure the correct speed and location to be posted.
7. The TMC will adjust the speed based on the trooper's request and document the following:
    - The time of the trooper's request,
    - The trooper's badge number,
    - The location on the corridor of the speed adjustment,

- The value of the speed adjustment, and
- The average and pace speeds based on the speed sensors.

8. The TMC Operator will notify the Patrol Dispatch, email the Maintenance Supervisors, the District Captain, the Division Lieutenants, and the staff coordinator for the affected area of the speed limit reduction.

Maintenance Foremen

If a WHP trooper is not on duty, a maintenance foreman may initiate a reduction in the legal speed based on visual inspection of the conditions. If conditions warrant a speed limit reduction, the following process must be followed.

1. The maintenance foreman must identify himself by his unit number and request assistance from the TMC.
2. The maintenance foreman identifies the area along the corridor with problems and asks that the posted speed be reduced to the pace speed. For example, "Interstate 80 in the westbound direction from MP 260.23 to MP 255.6".
3. The TMC Operator will repeat the request to the foreman to ensure the correct speed and location to be posted.
4. The TMC Operator will make the changes to the VSL based on the pace speed from the speed sensors and record the following:
    - The time of the maintenance foreman's request,
    - The foreman's unit number,
    - The value of the speed adjustment, and
    - The average and pace speeds from the speed sensors.
5. The TMC Operator will notify the Patrol Dispatch, email the Maintenance Supervisors, the District Captain, the Division Lieutenants, and the staff coordinator for the affected area of the speed limit reduction.

TMC Operator

If neither a trooper nor a maintenance foreman is on duty and the TMC lead operator recognizes a drop in the average speed along the corridor of 15 mph, the following process must be followed to change the legal speed limit along the corridor.

1. The TMC Lead Operator must confirm that no trooper or maintenance foreman is on duty on the segment in question.
2. The TMC Lead Operator will identify the area with the 15 mph speed decrease as indicated by the speed sensors.
3. The TMC Operator then makes the change to the VSL based on the pace speed from the speed sensors and records the following:
    - The time of the speed reduction,
    - The location of the speed adjustment,
    - The value of the speed adjustment, and
    - The average speed and pace speed from the speed sensors.
4. The TMC Operator will notify the Patrol Dispatch, email the Maintenance Supervisors, the District Captain, the Division Lieutenants, and the staff coordinator for the affected area of the speed limit reduction.
5. Increasing the speed, after it has been reduced due to weather conditions, or an incident, or at the end of the seasonal speed limit requires approval by a trooper. Then the posted legal speed can be changed by the TMC Operator.

An e-mail notification of speed limit changes made by any of the three groups mentioned above must be sent to the District 1 Road Update list every time the speed is adjusted along the corridor. The email should include the location and the value of the new speed limit.

Chapter 5 Data Sources

The following chapter is a description of the data sources used for this project including: all the variables that were collected, the data collection issues encountered during the project, and data availability.

5.1 Data Collection

Speed Sensors

There are 10 speed sensors installed along the project corridor. A list of the speed sensors and their MP can be found in Table 5-1. Until the end of September 2008, seven of the speed sensors were collecting data at five minute intervals, and three at fifteen minute intervals. The 15-minute interval sensors were at MPs 256.2, 260.3, and 288.3. During the rest of the project, data from the speed sensors were collected at five minute intervals. The speed sensors collect data for all four lanes of traffic and transmit this information to a central database at the WYDOT TMC at regular intervals.

Initially six of the speed sensors had communications with WYDOT but data from the remaining four sensors had to be manually downloaded. A list of the speed sensors and whether they had communications can be seen in

Table 5-1. For the 2009-2010 winter season all sensors had communication and were transmitting data. Some of the initial analysis steps did not have data available from the four sensors listed as “Manually Downloaded” in Table 5-1. The directional locations (westbound or eastbound) indicate what side of the road the sensor is on and is used to convert lane identification numbers to directional lanes. The speed sensors always label the closest lane as lane 1. The data was processed by researchers to convert lane ID

numbers to EB right, EB left, WB right, and WB left. The sensor at MP 272.5 was later moved to 273.1 to resolve the communication problem.

Table 5-1: Speed sensor information

Speed Senor (MP)	Directional location	Type of communications
288.3	WB	WYDOT
282.5	WB	Manually downloaded
278.13	WB	Manually downloaded
275.4	WB	WYDOT
272.5 (273.1)	WB	Manually downloaded
268.1	EB	Manually downloaded
266.4	WB	WYDOT
263.5	EB	WYDOT
260.3	WB	WYDOT
256.2	WB	WYDOT

The data collected by the six sensors with communication before November 19, 2008 were downloaded using Wavetronix software and then converted into a text file that was stored on WYDOT's central database. Each text file was then imported into Microsoft Excel. The manually downloaded data was in the form of a text file, which was also imported into Microsoft Excel.

There was one difference between the format of the data that came from the WYDOT computer and the manually downloaded data. The manually downloaded data placed vehicles into one of four length based classifications, C1 to C4. The data that came from the WYDOT computer was placed into one of eight vehicle length classifications. The vehicle lengths for the eight classifications were found using default values from Wavetronix and the data from both sources had to be processed so that all of it was formatted similarly.

An example of the speed sensor output from the Wavetronix software can be seen in Table 5-2. Because some speed sensors had communications with WYDOT and some

did not, each was given a Controller ID number. The LaneID column identifies the lane that the speed sensor collected data for; these differed depending on whether the speed sensor was on the north side of the road or the south. For a traveler heading westbound and passing the speed sensor, the WB right lane is the driving lane, and the WB left is the passing lane. The EB left is the passing lane on the eastbound side, and EB right is the driving lane on the eastbound side.

The Speed column is the average speed in miles per hour for that lane during the five minute evaluation period. The Vol column gives the total number of vehicles that passed the speed sensor in the five minute period. Occ denotes the occupancy, which is the percentage of time in which a vehicle occupied the space detected during the five minute period. The 85th column gives the 85th percentile speed of the vehicles passing the sensor during the 5 minute evaluation period. Headway is the average time in seconds between the time the front end of one vehicle passes the sensor and the time the rear end of the following vehicle passes the same sensor. Gap is the average time in seconds between the rear end of the first vehicle and the front end of the following vehicle. Columns C1 through C4 are the length classifications that the speed sensor assigns a vehicle. C1 denotes vehicles that are from 0 to 20 feet in length; C2 denotes vehicles that are from 20 to 40 feet; C3 denotes vehicles that are from 40 to 60 feet; and C4 denotes vehicles that are greater than 60 feet in length.

Although there are ten sensors along the corridor, not all of the sensors were working properly during the entire study period. The problems with the speed sensors will be discussed during the data availability section later in the chapter.

Table 5-2: Speed Sensor Output before November 19, 2008

Date	Time	Controller ID	Lane ID	Speed	Vol	Occ	85th	Headway	Gap	C1	C2	C3	C4
10/27	0:00	16	WB right	75	5	2	76	24	23.4	0	0	5	0
10/27	0:00	16	WB left	83	1	1	84	30	29.6	0	1	0	0
10/27	0:00	16	EB left	69	1	0	70	30	29.7	1	0	0	0
10/27	0:00	16	EB right	63	9	2	66	23.3	22.8	4	1	4	0
10/27	0:05	16	WB right	77	4	2	79	22.5	21.9	1	0	3	0
10/27	0:05	16	WB left	77	1	0	78	30	30	1	0	0	0
10/27	0:05	16	EB left	69	1	0	70	30	29.8	1	0	0	0
10/27	0:05	16	EB right	63	8	2	64	26.3	25.6	2	0	6	0
10/27	0:10	16	WB right	74	5	1	75	30	29.5	2	0	3	0
10/27	0:10	16	WB left	73	2	0	74	30	29.9	2	0	0	0
10/27	0:10	16	EB left	57	1	3	58	30	29	0	0	1	0
10/27	0:10	16	EB right	63	5	1	64	30	29.4	1	0	4	0
10/27	0:10	16	WB right	74	7	3	75	25.7	25	1	0	6	0

After November 19, 2008, the speed sensor data was processed using TransSuite® software that was purchased by WYDOT to analyze the speeds along the corridor in a real-time manner rather than storing it on a central database. This software runs a real-time speed map that is displayed at the TMC. There was a day gap in the speed sensor data that was available from Wavetronix and the availability in the data from TransSuite®, so there is no speed sensor data for November 19th, 2008.

The TransSuite® software currently does not record as many variables as the Wavetronix software, but future modifications to the software could add the missing variables. The TransSuite® output from these speed sensors includes the date and time, the Controller_ID, which specifies the location of the sensor, the Lane_ID, which

specifies the lane of travel the driver is in, the number of cars recorded in the lane during that five minute period, the vehicle occupancy during that period, and the average speed. Table 5-3 is a sample of the output from the speed sensor. The major differences between the two software outputs is that the current TransSuite® software does not calculate 85th percentile speeds and does not provide vehicle classification.

Table 5-3: Sample speed sensor output after November 19, 2008

Date/Time	Controller_ID	Lane_ID	Volume	Occ	Avg Spd
11/20/2008 11:30	21	WB left	5	3.63	64.3
11/20/2008 11:30	21	WB right	0	0	0
11/20/2008 11:30	21	EB right	0	0	0
11/20/2008 11:30	21	EB left	1	0.21	60.1
11/20/2008 11:35	21	WB right	5	0.31	76.1
11/20/2008 11:35	21	EB right	0	0	0
11/20/2008 11:35	21	EB left	4	0.21	63.8
11/20/2008 11:35	21	WB left	23	2.64	66.3
11/20/2008 11:40	21	WB left	29	3.25	62.5
11/20/2008 11:40	21	WB right	5	0.22	69.0
11/20/2008 11:40	21	EB left	0	0	0
11/20/2008 11:40	21	EB right	0	0	43.8
11/20/2008 11:45	21	WB left	47	5.43	63.2
11/20/2008 11:45	21	WB right	9	0.93	69.3
11/20/2008 11:45	21	EB right	0	0	43.8
11/20/2008 11:45	21	EB left	1	0.08	63.4

For some of the analyses it was necessary to overcome the issues with binned data and the TransSuite® software not providing 85th percentile speeds and vehicle classifications. To do this the speed sensors could be put into a vehicle log mode that

creates a data record for each individual vehicle that passes the sensor. This data log also records vehicle length so the records could be sorted using a length based vehicle classification. For this project vehicles less than 20 feet in length were classified as cars and any vehicle over 20 feet was classified as trucks. Putting the sensor into the individual vehicle log mode disables the sensor for use in the TMC speed map. This made it necessary to limit the number of sensors that were put into this mode and the duration of time they were left in the log mode. Chapter 8 discusses the analyses performed with this individual data.

RWIS

The Road Weather Information Systems (RWIS) station on this corridor is located at MP 272.0 next to the Arlington Interchange. The location of the RWIS station can be seen on the project corridor map in Figure 4-1 in Chapter 4. Data is collected by the RWIS station every five minutes. As mentioned in Chapter 4 additional RWIS are being installed along the corridor but none of these RWIS become operational during this research project.

The RWIS station provides information about the pavement surface and precipitation history as well as the atmospheric conditions. An example of the RWIS output for 11/4/2008 can be found in Table 5-4.

Table 5-4: Sample RWIS output

Date	Time	Sf Status	Sf Temp (°F)	Chem	Conduct	Air Temp (°F)	RH	Dew Point	Avg Wind Speed (MPH)	Gust Wind Speed (MPH)	Wind Direct	Visi-Bility (ft)
11/4	16:45	Wet	41.7	5	65535	44	39	20	24	41	SW	15840
11/4	16:50	Wet	41.5	5	65535	44	38	20	27	49	SW	14784
11/4	16:55	Wet	41.7	5	65535	44	38	20	34	49	SW	15315
11/4	17:00	Wet	41.5	5	65535	44	38	20	32	52	SW	15840

The SfStatus describes the surface status of the pavement. The status could be one of eight different conditions: dry, trace moisture, wet, chemically wet, ice, ice

warning, ice watch, or error. Dry meant that there was an absence of any type of moisture on the surface sensor. Trace Moisture meant that there were thin or spotty films of moisture above freezing temperature (32°F). Wet meant that there was a continuous film of moisture on the pavement sensor, and the surface temperature was above freezing. Chemically wet meant that there was a continuous film of water and ice mixture, at or below freezing, with enough chemicals in the mixture to keep it from freezing. Ice meant that there was moisture on the sensor that was below freezing temperature. Ice warning meant that there was a possibility for the moisture on the road to turn to ice, and ice watch occurred when the surface temperature was at freezing point. An error reading meant that the surface sensor was not operating so there was no reading at that time.

The SfTemp was the temperature of the pavement sensor. The ChemFactor reading was the percent of chemical saturation in the moisture on a scale from 0 to 100. This is reported when the surface status is wet, Chemical Wet, or Ice Warning. Conduct is the conductance of the ice/liquid mixture on the pavement.

Air temperature is the first of the atmospheric readings at the RWIS site. Relative humidity (RH) is the percent of moisture in the air. The higher the relative humidity value is, the more moisture there is in the air. Dew Point is the temperature at which the air becomes saturated as it cools. Average Wind Speed is the average speed of the wind during the five minute period. Wind Gust Speed is the maximum wind speed measured during the five minute period. Wind direction is the average wind direction over the five minute period and is referenced in 8 directions: N, NE, E, SE, S, SW, W, and NW. Visibility is the average distance that the driver can see along the corridor in feet.

The RWIS data was more reliable than the speed sensor data over the course of the study. There were a few days during the data collection that the RWIS station would lose communication and would not collect data, but issues were usually resolved quickly. From May 26, 2008 to August 25, 2008 there was no RWIS data. There were also several periods when the RWIS visibility sensor stopped working.

RWIS data was also available on WYDOT's central database. The pavement and atmospheric data are contained in different records. The data is exported one day at a time by copying the desired data onto a clipboard, pasting it into a word processor, and converting it into a text file. Since the pavement data and atmospheric data are separate records, the data must then be merged. Using a Visual Basic script in Microsoft Excel, one day of data at a time is merged together. The data was then compiled into a master spreadsheet.

VSL Database

Every VSL sign change in the corridor is recorded into the VSL Event Log. The Event Log documents the milepost of the sign where the VSL was changed, the time and date of the speed limit change, and the event code that corresponds to the new speed limit value that was posted. The event codes are shown in Table 5-5. The TMC operators have the ability to show a speed limit with or without beacons but TMC policy recommends always using the beacons when a speed reduction is in place.

The first day that the original twenty VSL signs were used on the corridor was February 17, 2009. This data was then merged with the speed sensor data that was downloaded from the TransSuite® software for the data analyses described in later chapters.

Table 5-5: VSL codes

Code	Setting
#1	35 no beacons
#2	40 no beacons
#3	45 no beacons
#4	50 no beacons
#5	55 no beacons
#6	60 no beacons
#7	65 no beacons
#8	75 no beacons
#9	35 Reduced and beacons
#10	40 Reduced and beacons
#11	45 Reduced and beacons
#12	50 Reduced and beacons
#13	55 Reduced and beacons
#14	60 Reduced and beacons
#15	65 Reduced and beacons

In order to run the analyses, each speed sensor was paired with the closest upstream VSL sign. Since WYDOT is able to change the speed on each sign pair independently of the other sign pairs along the corridor, this allowed analysis to be done to determine how drivers responded to the speed posted on the sign that they had last seen.

Table 5-6 shows the VSL location in relation to the speed sensors. The VSL sign is the sign that drivers see before they drive past the reference speed sensor. The distance column lists the distance in miles from the VSL sign to the speed sensor. The four new VSL signs are not included in this table since they became operational at various times during the 2009-2010 winter season.

Table 5-6: VSL signs related to Speed Sensors

Speed Sensor MP	EB VSL MP	Upstream EB Distance	WB VSL MP	Upstream WB Distance
256.20	256.17	0.03	259.77	3.57
260.30	256.17	4.13	266.58	6.28
263.50	262.40	1.10	266.58	3.08
266.40	262.40	4.00	266.58	0.18
268.10	267.71	0.39	271.80	3.70
272.00	267.71	4.29	279.36	7.36
275.40	273.85	1.55	279.36	3.96
278.13	273.85	4.28	279.36	1.23
282.50	280.36	2.14	289.50	7.00
288.30	280.36	7.94	289.50	1.20

5.2 Data Availability and Collection Issues

Since the legal posted speed limit changed during the project, the data was split into two sets. The first is the 75 mph set, which contains the data that was collected when the seasonal speed limit was not in effect. An initial 75 mph data set without the VSL system was complied for September 1, 2008 to September 30, 2008.

During this period, data from six speed sensors was available. One of the speed sensors with communications was reporting only zeros during that period (MP 275.4). Three of the sensors with data that had to be manually downloaded were broken during this time. One of the sensor heads malfunctioned and no data could be retrieved from the sensor (MP 278.13). One sensor lost all of the September data, even though the head was not completely full. It was determined that the sensor head was having storage problems (MP 282.5). The last sensor was not installed properly, and the data was not useable (MP 268.1).

The second set of data was collected after the seasonal speed limit of 65 mph was implemented and before the VSL system was installed. The 65 mph data was collected from October 22, 2008 to November 19, 2008. On October 15, 2008, the seasonal speed limit was implemented, but there were still some data collection problems occurring. On October 22, 2008, all of the data collection issues had been resolved, and all sensors were working. On November 19, 2008 WYDOT started using TransSuite® software to manage the speed sensor data. This software allows WYDOT to look at the speeds along the corridor in a more real-time manner.

During this period, all six of the sensors with WYDOT communications were in operation. Two of the manually downloaded sensors were still not operating during this period. These two sensors were the one with the malfunctioning sensor head (MP 278.13), and the one that was not installed properly (MP 268.1).

5.3 Merged Data Sets

Using the speed sensor data as the base records, the RWIS data was appended to each speed sensor record using the VLOOKUP function in Microsoft Excel. Occasionally the RWIS station lost communication and there was no data to append to the speed sensor data. On these occasions, the weather data closest to the speed sensor time was used. The maximum difference allowed between the speed and the RWIS data was an hour.

After the data was merged together, the RWIS data was analyzed to determine whether each day had ideal data or non-ideal data. The ideal data was used to establish baseline speeds along the corridor. The non-ideal data was used to analyze the effects of the weather variables on driver's speeds.

The criteria that were used to determine if the data was ideal or non-ideal were the SfStatus, the GustWindSpeed, and the visibility along the corridor. If the SfStatus was any other condition than dry, the day was considered non-ideal. WYDOT issues warnings on DMSs and their website when the Gust Wind Speed is over 45 mph, so any day with wind speeds higher than that were non-ideal. According to the studies in presented in Chapter 2, many agencies feel that visibility values less than or equal to 500 feet can result in problems on the roadway. So, ideal data has visibility lengths greater than 500 feet.

The 75 mph data set had twelve ideal days of data and eighteen non-ideal days of data. The first set of 65 mph data had seven ideal days of data and twenty days of non-ideal data. The ideal data was merged into a single spreadsheet in order to find the baseline speeds along the corridor.

Modeling was done on the combined data set, including the ideal and non-ideal data, to determine the effects of the weather variables on the speeds. The purpose of this analysis is to determine if one RWIS station is accurately depicting what is happening at each of the sensors.

A data set was also created for the information collected during the time when the Variable Speed Limit System was initially being utilized along the corridor. A month of speed sensor data from February 14, 2009 to April 14, 2009 was collected and combined with the Variable Speed Limit and the RWIS databases to determine if the Variable Speed Limit changes were actually impacting driver speeds.

A similar analysis was repeated for the period of October 15, 2009 to December 15, 2009 to see if the speed impact results were comparable for a period after frequent

drivers would have become accustomed to the VSL system. This dataset was also used exclusively for developing the draft VSL control strategy.

The results and conclusions made from modeling will be discussed in Chapter 6.

Chapter 6 VSL System Use

VSL sign data from the VSL database for the corridor from MP 235 to 295 was obtained for three time periods. The first time period was the winter period from February 18, 2009 to April 14, 2009 when there was a seasonal speed limit of 65 mph in place on the corridor. This time period shows the use of the system during the initial implementation of the VSL system. The second time period was the summer period from April 15, 2009 to October 14, 2009 when the regular speed limit with no VSL use was 75 mph. The last time period was the winter period from October 15, 2009 to April 14, 2010 when there was a seasonal speed limit of 65 mph in place on the corridor. The second and third time periods show the use of the system during the first full year of system use.

The data collected included all of the VSL system changes during each time period at each mile marker in the eastbound and westbound directions. The data was converted into Excel files and analyzed. To analyze the VSL system tables and graphs were created to show the frequency, cumulative duration, and average duration for each time period and each direction of travel. The following sections will discuss each of the three time periods. Only westbound figures are shown in this chapter. Eastbound graphs can be found in Appendix B.

6.1 Initial VSL Implementation (Feb 18, 2009-April 14, 2009)

The frequency, cumulative duration, and average duration of VSL implementation were calculated to analyze how the system was used during the first two months of implementation. Tables and corresponding graphs were created for the eastbound and westbound directions for each time period. The data obtained from this time period can be seen in Table 6-1, which contains data for eastbound and westbound directions at each

milepost. The percent of time displayed column shows what percent of the almost two month period different speed limits were applied to the corridor.

Table 6-1: Initial Use of VSL System (February 18, 2009 to April 14, 2009)

Westbound					Eastbound				
MP 259.77					**MP 256.17**				
Speed	Freq	Cum. Duration	Avg. Duration	% of Time Displayed	Speed	Freq.	Cum. Duration	Avg. Duration	% of Time Displayed
35	3	12:31:11	4:10:24	0.92	35	4	12:44:25	3:11:06	0.94
40	4	48:47:40	12:11:55	3.58	40	3	41:07:32	13:42:31	3.02
45	13	350:06:03	26:55:51	25.71	45	11	102:13:44	9:17:37	7.50
50	9	72:59:15	8:06:35	5.36	50	11	70:25:41	6:24:09	5.17
55	14	47:37:51	3:24:08	3.50	55	13	43:20:40	3:20:03	3.18
60	1	8:04:57	8:04:57	0.59	60	2	8:59:07	4:29:33	0.66
65*	22	821:40:52	37:20:57	60.34	65*	24	1083:29:14	45:08:43	79.53
MP 266.58					**MP 262.4**				
Speed	Freq	Cum. Duration	Avg. Duration	% of Time Displayed	Speed	Freq.	Cum. Duration	Avg. Duration	% of Time Displayed
35	6	19:17:50	3:12:58	1.42	35	8	21:40:46	2:42:36	1.59
40	4	58:59:50	14:44:58	4.35	40	4	58:34:03	14:38:31	4.29
45	11	95:09:07	8:39:01	7.01	45	10	95:49:07	9:34:55	7.03
50	13	326:54:57	25:08:51	24.08	50	14	70:36:58	5:02:38	5.18
55	12	41:29:19	3:27:27	3.06	55	14	70:44:06	5:03:09	5.19
60	2	28:28:03	14:14:02	2.10	60	2	19:12:19	9:36:09	1.41
65*	22	787:29:56	35:47:43	58.00	65*	24	1027:16:09	42:48:10	75.32
MP 271.8					**MP 267.71**				
Speed	Freq	Cum. Duration	Avg. Duration	% of Time Displayed	Speed	Freq.	Cum. Duration	Avg. Duration	% of Time Displayed
35	9	71:33:31	7:57:03	5.25	35	8	37:24:54	4:40:37	2.76
40	3	56:44:14	18:54:45	4.16	40	4	62:53:26	15:43:21	4.64
45	11	94:57:36	8:37:58	6.96	45	10	116:20:46	11:38:05	8.58
50	14	96:09:39	6:52:07	7.05	50	14	93:45:53	6:41:51	6.91
55	18	61:35:38	3:25:19	4.52	55	16	79:32:25	4:58:17	5.87
60	2	8:53:02	4:26:31	0.65	60	2	19:07:59	9:33:59	1.41
65*	23	973:32:13	42:19:40	71.40	65*	26	946:59:55	36:25:23	69.83
MP 279.36					**MP 273.85**				
Speed	Freq	Cum. Duration	Avg. Duration	% of Time Displayed	Speed	Freq.	Cum. Duration	Avg. Duration	% of Time Displayed
35	8	43:08:02	5:23:30	3.17	35	10	67:21:54	6:44:11	4.97
40	1	42:48:24	42:48:24	3.14	40	3	43:41:20	14:33:47	3.23
45	10	73:16:50	7:19:41	5.38	45	11	87:45:15	7:58:40	6.48
50	11	67:01:31	6:05:36	4.92	50	13	57:54:12	4:27:15	4.28
55	17	102:42:46	6:02:31	7.54	55	15	65:33:01	4:22:12	4.84

60	2	9:41:24	4:50:42	0.71	60	2	8:00:07	4:00:03	0.59
65*	25	1023:49:47	40:57:11	75.14	65*	26	1024:05:41	39:23:18	75.61
MP 289.5					**MP 280.36**				
Speed	Freq	Cum. Duration	Avg. Duration	% of Time Displayed	Speed	Freq.	Cum. Duration	Avg. Duration	% of Time Displayed
35	2	8:44:51	4:22:25	0.64	35	5	30:22:53	6:04:35	2.24
40	2	343:02:27	171:31:14	25.17	40	2	57:59:24	28:59:42	4.27
45	4	38:51:38	9:42:54	2.85	45	7	57:48:44	8:15:32	4.26
50	3	26:01:58	8:40:39	1.91	50	6	38:50:28	6:28:25	2.86
55	11	66:41:43	6:03:48	4.89	55	9	48:24:33	5:22:44	3.57
60	0	0:00:00	0:00:00	0.00	60	0	0:00:00	0:00:00	0.00
65*	15	879:42:59	58:38:52	64.54	65*	23	1123:29:31	48:50:51	82.80
*Seasonal speed limit in effect so maximum speed during this period was 65 mph									

This table shows that the VSL system was used extensively during the initial weeks of implementation, as many severe storms hit the corridor. The table also shows the use of the system varies considerably by duration and milepost.

Figure 6-1 shows the speed versus frequency distribution for the first winter period. The speeds of 65, 55, 45, and 35 mph are used very frequently, while 60 mph was used very rarely, if at all. Milepost 289.5 had reduced speeds displayed less frequently than the other mileposts.

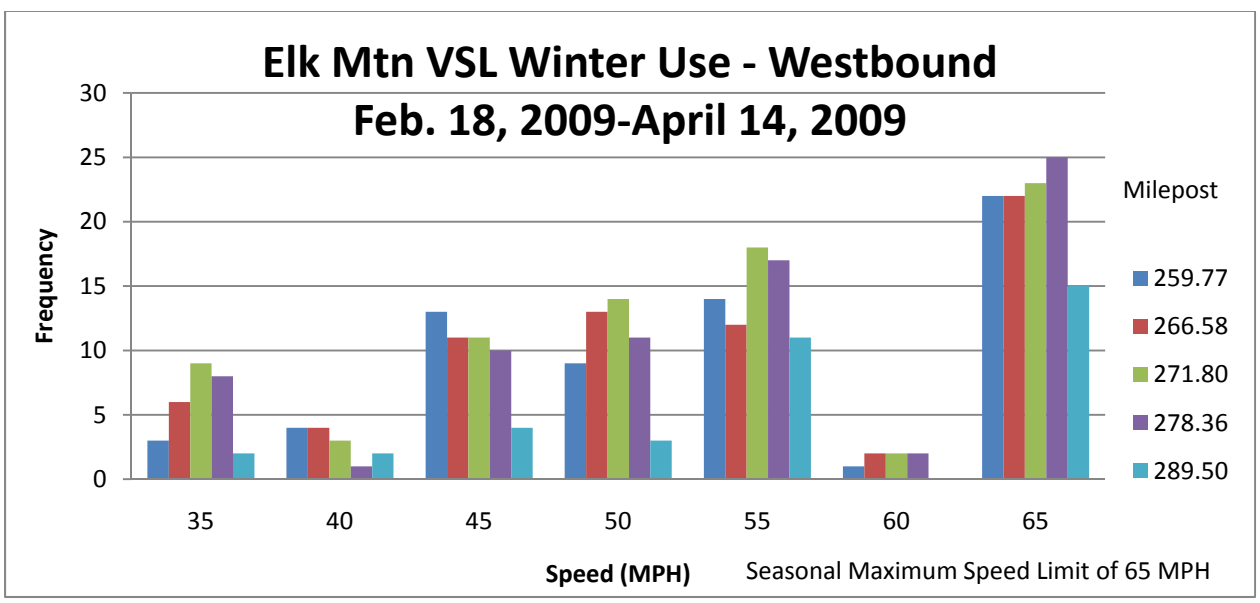

Figure 6-1: Posted Speed versus Frequency (Initial Winter)

Figure 6-2 and Figure 6-3 show the speed versus cumulative duration and speed versus average duration respectively. Figure 6-2 shows three different cases where a particular speed was used much more than any other speed. Comparing the values from Figure 6-2 to those of Figure 6-3 indicates that a speed of 40 mph was used at milepost 289.5 for an extended period of time.

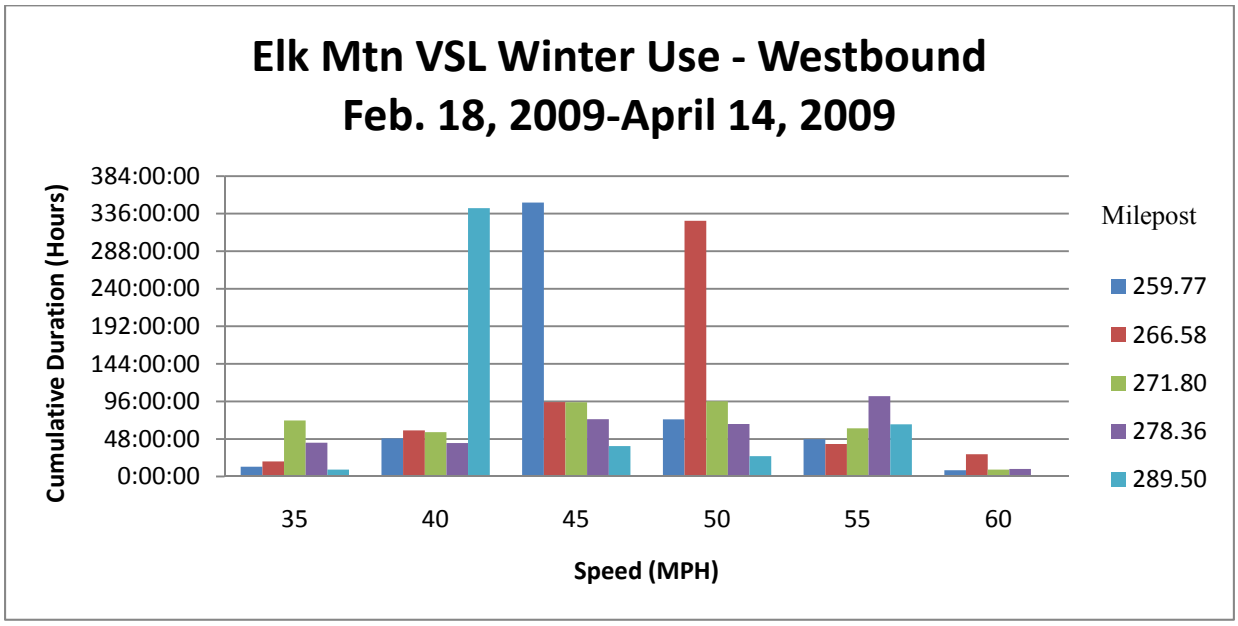

Figure 6-2: Posted Speed versus Cumulative Duration (Initial Winter)

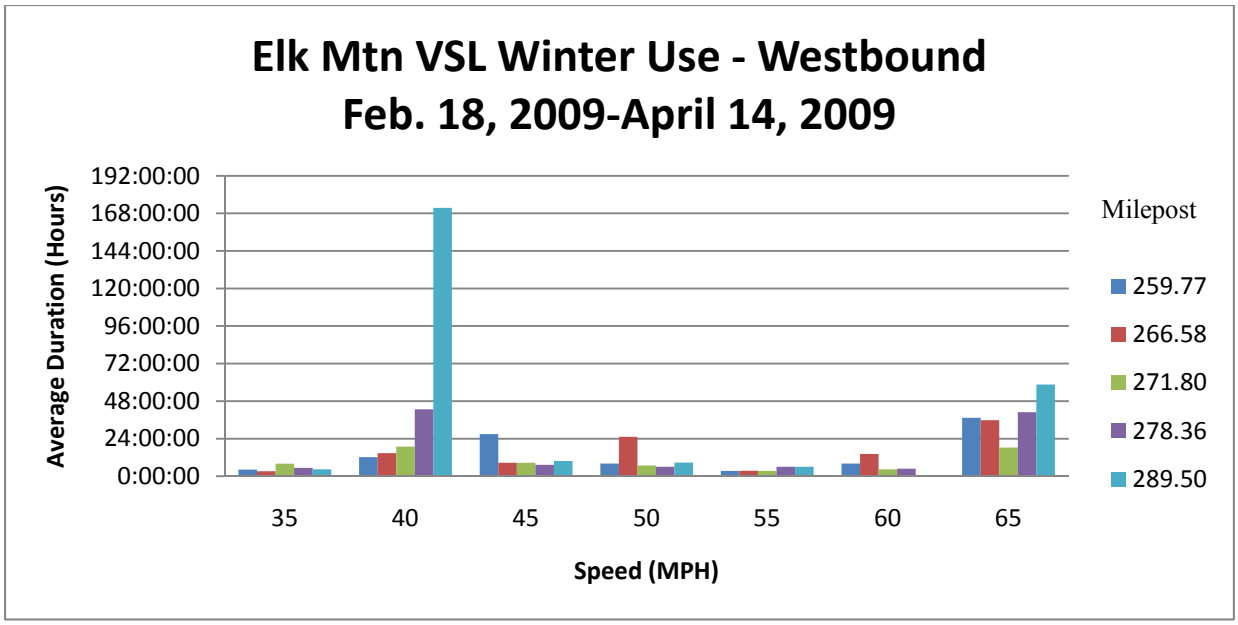

Figure 6-3: Posted Speed versus Average Duration (Initial Winter)

6.2 VSL Summer Implementation (April 15, 2009 to October 14, 2009)

The first summer the VSL was used was during 2009 from April 15 to October 14 where the maximum speed limit was 75 mph. The data for the summer period used to generate the graphs can be seen in Table 6-2. Compared to the initial months of VSL implementation the system was used far less due to less frequent weather events.

Table 6-2: Summer Use of VSL System (April 15, 2009 to October 14, 2009)

Westbound					Eastbound				
MP 259.77					MP 256.17				
Speed	Freq	Cum Duration	Avg. Duration	% of Time Displayed	Speed	Freq	Cum Duration	Avg. Duration	% of Time Displayed
35	0	0:00:00	0:00:00	0	35	1	0:01:13	0:01:13	0
40	1	7:41:04	7:41:04	0.18	40	4	8:12:23	2:03:06	0.19
45	3	32:51:13	10:57:04	0.75	45	2	33:40:56	16:50:28	0.77
50	0	0:00:00	0:00:00	0	50	0	0:00:00	0:00:00	0
55	7	29:47:50	4:15:24	0.68	55	9	31:37:48	3:30:52	0.72
60	2	13:21:24	6:40:42	0.3	60	3	13:39:24	4:33:08	0.31
65	11	19:54:28	1:48:35	0.45	65	9	19:36:41	2:10:45	0.45
75	20	4279:17:04	213:57:51	97.64	75	20	4276:04:40	213:48:14	97.56

MP 266.58					MP 262.4				
Speed	Freq	Cum Duration	Avg. Duration	% of Time Displayed	Speed	Freq	Cum Duration	Avg. Duration	% of Time Displayed
35	0	0:00:00	0:00:00	0	35	0	0:00:00	0:00:00	0
40	3	8:10:59	2:43:40	0.19	40	3	8:10:58	2:43:39	0.19
45	3	35:58:21	11:59:27	0.82	45	2	33:41:11	16:50:35	0.77
50	0	0:00:00	0:00:00	0	50	0	0:00:00	0:00:00	0
55	10	36:06:14	3:36:37	0.82	55	10	36:05:08	3:36:31	0.82
60	3	13:37:28	4:32:29	0.31	60	3	13:37:47	4:32:36	0.31
65	10	18:48:18	1:52:50	0.43	65	9	19:46:43	2:11:51	0.45
75	17	4270:11:42	251:11:17	97.43	75	20	4271:31:07	213:34:33	97.46
MP 271.8					**MP 267.71**				
Speed	Freq	Cum Duration	Avg. Duration	% of Time Displayed	Speed	Freq	Cum Duration	Avg. Duration	% of Time Displayed
35	1	2:03:45	2:03:45	0.05	35	0	0:00:00	0:00:00	0
40	2	8:09:52	4:04:56	0.19	40	3	8:11:03	2:43:41	0.19
45	2	33:34:36	16:47:18	0.77	45	2	33:38:49	16:49:25	0.77
50	0	0:00:00	0:00:00	0	50	0	0:00:00	0:00:00	0
55	10	31:47:12	3:10:43	0.73	55	9	30:54:44	3:26:05	0.71
60	5	16:23:25	3:16:41	0.37	60	3	14:35:40	4:51:53	0.33
65	10	23:40:43	2:22:04	0.54	65	9	29:29:14	3:16:35	0.67
75	17	4267:13:22	251:00:47	97.36	75	15	4266:03:32	284:24:14	97.33
MP 279.36					**MP 273.85**				
Speed	Freq	Cum Duration	Avg. Duration	% of Time Displayed	Speed	Freq	Cum Duration	Avg. Duration	% of Time Displayed
35	0	0:00:00	0:00:00	0	35	0	0:00:00	0:00:00	0
40	2	8:09:48	4:04:54	0.19	40	2	8:09:42	4:04:51	0.19
45	3	35:50:52	11:56:57	0.82	45	3	37:38:08	12:32:43	0.86
50	0	0:00:00	0:00:00	0	50	0	0:00:00	0:00:00	0
55	9	27:04:22	3:00:29	0.62	55	9	26:02:43	2:53:38	0.59
60	3	19:19:52	6:26:37	0.44	60	5	19:31:06	3:54:13	0.45
65	8	26:33:19	3:19:10	0.61	65	8	24:12:47	3:01:36	0.55
75	15	4265:54:53	284:23:40	97.33	75	15	4267:18:39	284:29:15	97.36
MP 289.5					**MP 280.36**				
Speed	Freq	Cum Duration	Avg. Duration	% of Time Displayed	Speed	Freq	Cum Duration	Avg. Duration	% of Time Displayed
35	0	0:00:00	0	0	35	0	0:00:00	0:00:00	0
40	2	10:01:17	5:00:39	0.23	40	2	8:09:15	4:04:37	0.19
45	3	35:34:42	11:51:34	0.81	45	4	35:34:40	8:53:40	0.81
50	0	0:00:00	0	0	50	0	0:00:00	0:00:00	0
55	1	0:56:20	0:56:20	0.02	55	6	19:03:28	3:10:35	0.43
60	2	17:09:49	8:34:54	0.39	60	3	19:19:43	6:26:34	0.44
65	5	22:58:52	4:35:46	0.52	65	9	24:17:49	2:41:59	0.55
75	9	4296:12:04	477:21:20	98.02	75	16	4276:28:01	267:16:45	97.57

Figure 6-4 shows the posted speed versus frequency graph for the summer period in the westbound direction. The summer period speed frequency graphs have a similar pattern with 65, 55, and 45 mph being implemented more frequently than 60, 50, and 40 mph. A speed of 70 mph is not an option as 70 mph is not printed on the VSL sign scrolls.

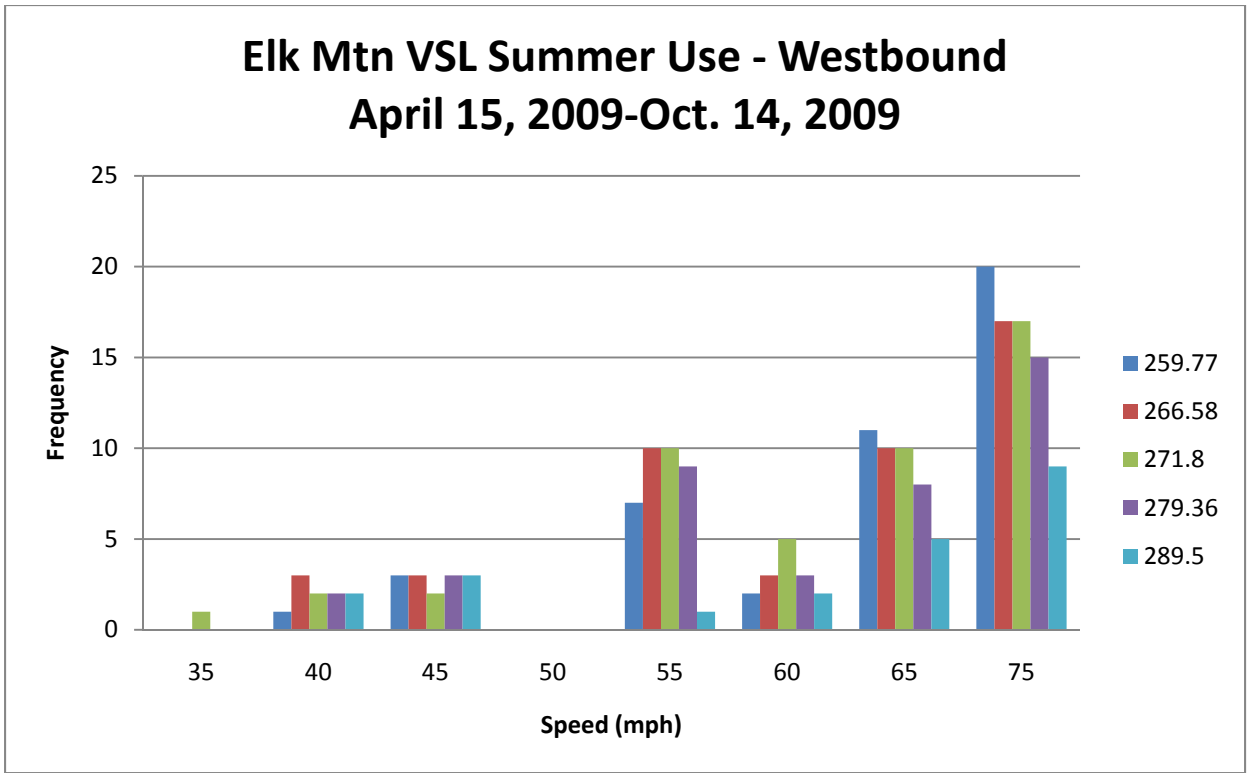

Figure 6-4: Posted Speed vs. Frequency (Summer)

The summer period graph of posted speed versus cumulative duration looks similar to the winter period and can be seen in Figure 6-5, which only shows speeds from 35 mph up to 65 mph and does not include data from 75 mph. The data was omitted from the graph as the cumulative duration for the 75 mph speed limit was very large because it was the default speed for this time period. The information not displayed can be found in Table 6-2.

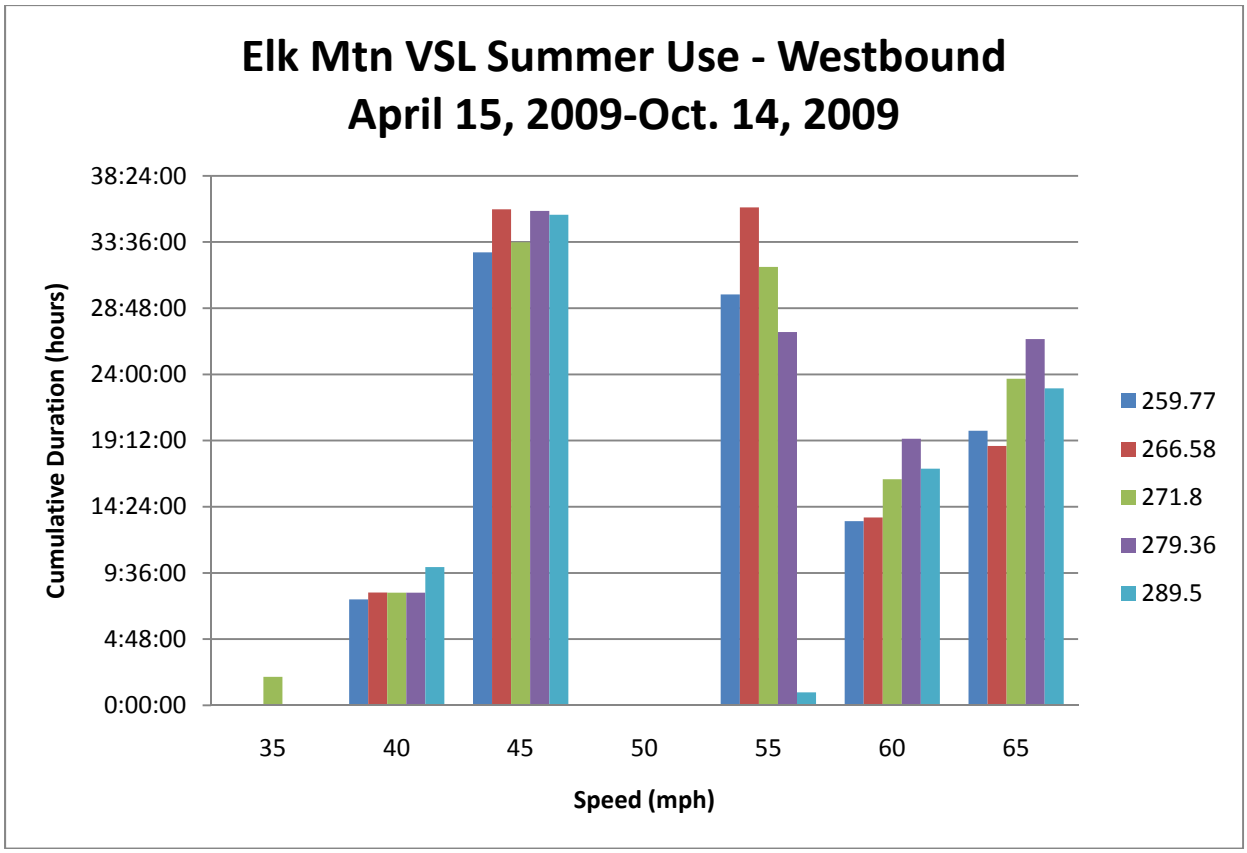

Figure 6-5: Posted Speed vs. Cumulative Duration (Summer)

Figure 6-6 is an example of the average duration graphs from the summer period where the 75 mph data has been removed for the same reason it was removed from the cumulative duration graphs. For the summer period graphs of cumulative and average duration there were a few outliers that were removed from the data set. Adjustments were made to the VSL data from milepost 289.5 in the westbound direction. Events were removed or adjusted on the following dates.

- May 20, 2009- event removed.
- July 4, 2009- adjustment from 65 to 75 mph.
- July 13, 2009- event removed.
- July 29, 2009- event removed.
- August 19, 2009- event removed.

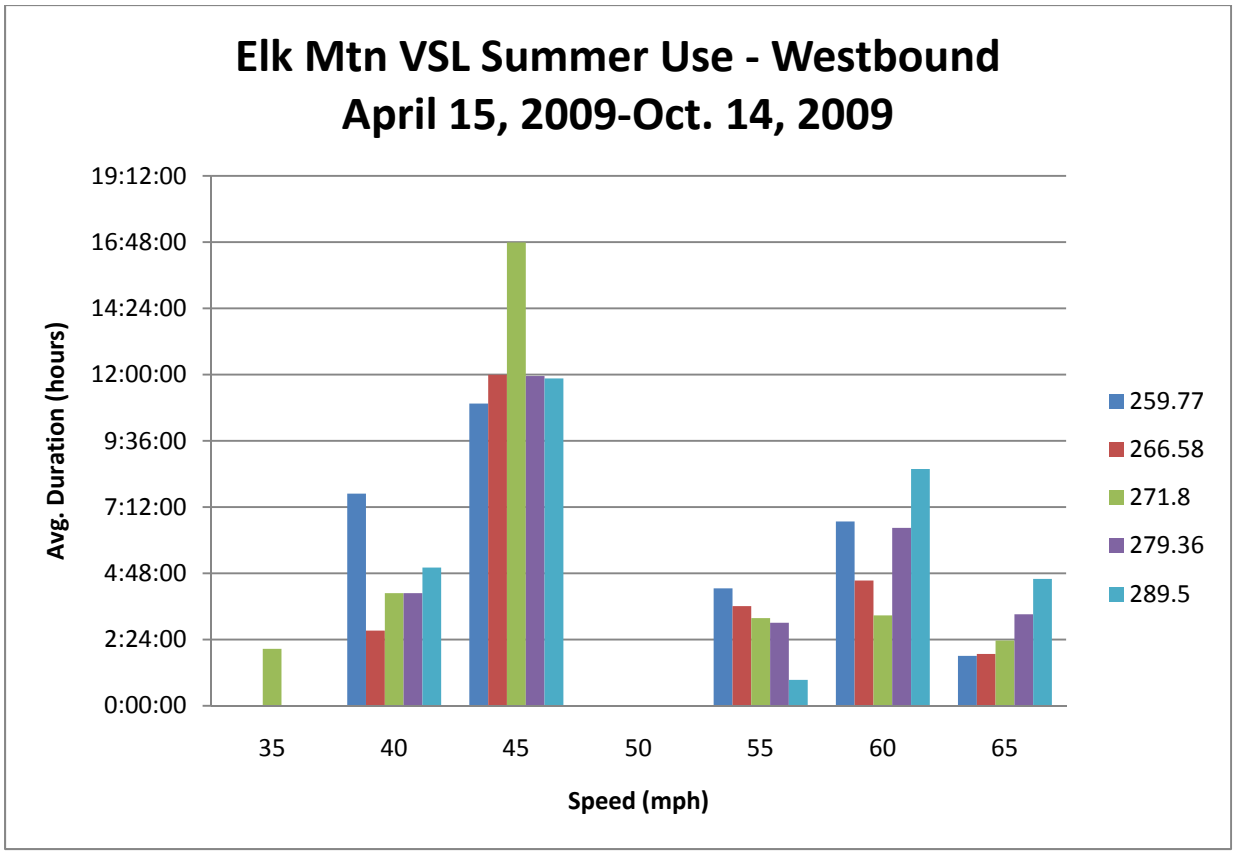

Figure 6-6: Posted Speed vs. Average Duration (Summer)

6.3 VSL Winter Implementation (October 15, 2009 to April 14, 2010)

Table 6-3 contains all the data used to create the graphs for the time period from October 15, 2009 to April 14, 2010 for both the eastbound and westbound directions. Figure 6-7: Posted Speed vs. Frequency (Winter) is an example of what the frequency graphs look like and shows the frequency of each specific speed that was implemented at each milepost.

Table 6-3: Use of VSL System (October 15, 2009 through April 14, 2010)

Westbound					Eastbound				
MP 259.77					**MP 256.17**				
Speed	Freq	Cum Duration	Avg. Duration	% of Time Displayed	Speed	Freq	Cum Duration	Avg. Duration	% of Time Displayed
35	6	73:01:33	12:10:15	1.68	35	7	73:46:15	10:32:19	1.69
40	2	3:03:49	1:31:54	0.07	40	1	0:22:14	0:22:14	0.01
45	22	226:37:57	10:18:05	5.2	45	22	229:30:08	10:25:55	5.26
50	13	100:25:46	7:43:31	2.3	50	14	106:12:29	7:35:11	2.44
55	45	289:00:27	6:25:21	6.63	55	46	296:29:49	6:26:44	6.8
60	15	55:18:57	3:41:16	1.27	60	14	65:53:36	4:42:24	1.51
65*	55	3612:11:13	65:40:34	82.85	65*	51	3587:25:11	70:20:30	82.29
MP 266.58					**MP 262.4**				
Speed	Freq	Cum Duration	Avg. Duration	% of Time Displayed	Speed	Freq	Cum Duration	Avg. Duration	% of Time Displayed
35	7	75:50:01	10:50:00	1.74	35	8	77:47:19	9:43:25	1.78
40	4	20:02:34	5:00:39	0.46	40	2	19:18:42	9:39:21	0.44
45	24	259:23:36	10:48:29	5.95	45	25	278:28:24	11:08:20	6.39
50	18	113:52:22	6:19:35	2.61	50	17	97:57:03	5:45:43	2.25
55	43	247:29:56	5:45:21	5.68	55	45	267:54:09	5:57:12	6.15
60	18	80:35:30	4:28:38	1.85	60	18	72:34:26	4:01:55	1.66
65*	52	3562:25:43	68:30:30	81.71	65*	55	3545:39:39	64:28:00	81.33
MP 271.8					**MP 267.71**				
Speed	Freq	Cum Duration	Avg. Duration	% of Time Displayed	Speed	Freq	Cum Duration	Avg. Duration	% of Time Displayed
35	7	78:23:53	11:11:59	1.9	35	9	82:44:57	9:11:40	1.9
40	2	0:12:16	0:06:08	0	40	3	0:56:26	0:18:49	0.02
45	25	267:58:19	10:43:08	6.5	45	24	266:45:50	11:06:55	6.12
50	16	541:30:40	33:50:40	13.13	50	16	321:50:35	20:06:55	7.38
55	50	257:27:43	5:08:57	6.24	55	52	317:53:00	6:06:47	7.29
60	21	74:34:36	3:33:05	1.81	60	22	78:01:52	3:32:49	1.79
65*	48	2905:01:03	60:31:16	70.42	65*	57	3291:27:02	57:44:41	75.5
MP 279.36					**MP 273.85**				
Speed	Freq	Cum Duration	Avg. Duration	% of Time Displayed	Speed	Freq	Cum Duration	Avg. Duration	% of Time Displayed
35	7	73:16:56	10:28:08	1.68	35	9	83:04:32	9:13:50	1.91
40	2	5:21:59	2:40:59	0.12	40	2	5:23:57	2:41:58	0.12
45	24	225:41:20	9:24:13	5.18	45	24	228:39:04	9:31:38	5.24
50	16	156:53:52	9:48:22	3.6	50	16	207:44:55	12:59:03	4.77
55	50	254:55:32	5:05:55	5.85	55	48	257:49:19	5:22:17	5.91

60	19	81:23:41	4:17:02	1.87	60	19	113:35:30	5:58:43	2.61
65*	52	3562:06:23	68:30:07	81.71	65*	50	3463:22:26	69:16:03	79.44
MP 289.5					**MP 280.36**				
Speed	Freq	Cum Duration	Avg. Duration	% of Time Displayed	Speed	Freq	Cum Duration	Avg. Duration	% of Time Displayed
35	6	69:06:44	11:31:07	1.59	35	7	69:44:44	9:57:49	1.6
40	2	57:31:43	28:45:51	1.32	40	3	62:52:55	20:57:38	1.44
45	23	112:55:30	4:54:35	2.59	45	19	125:17:08	6:35:38	2.87
50	17	87:56:02	5:10:21	2.02	50	13	91:40:38	7:03:08	2.1
55	41	176:40:30	4:18:33	4.05	55	41	225:30:06	5:30:00	5.17
60	17	36:58:08	2:10:29	0.85	60	9	53:46:50	5:58:32	1.23
65*	49	3818:31:06	77:55:44	87.59	65*	44	3730:47:22	84:47:26	85.58

*Seasonal speed limit in effect so maximum speed during this period was 65 mph

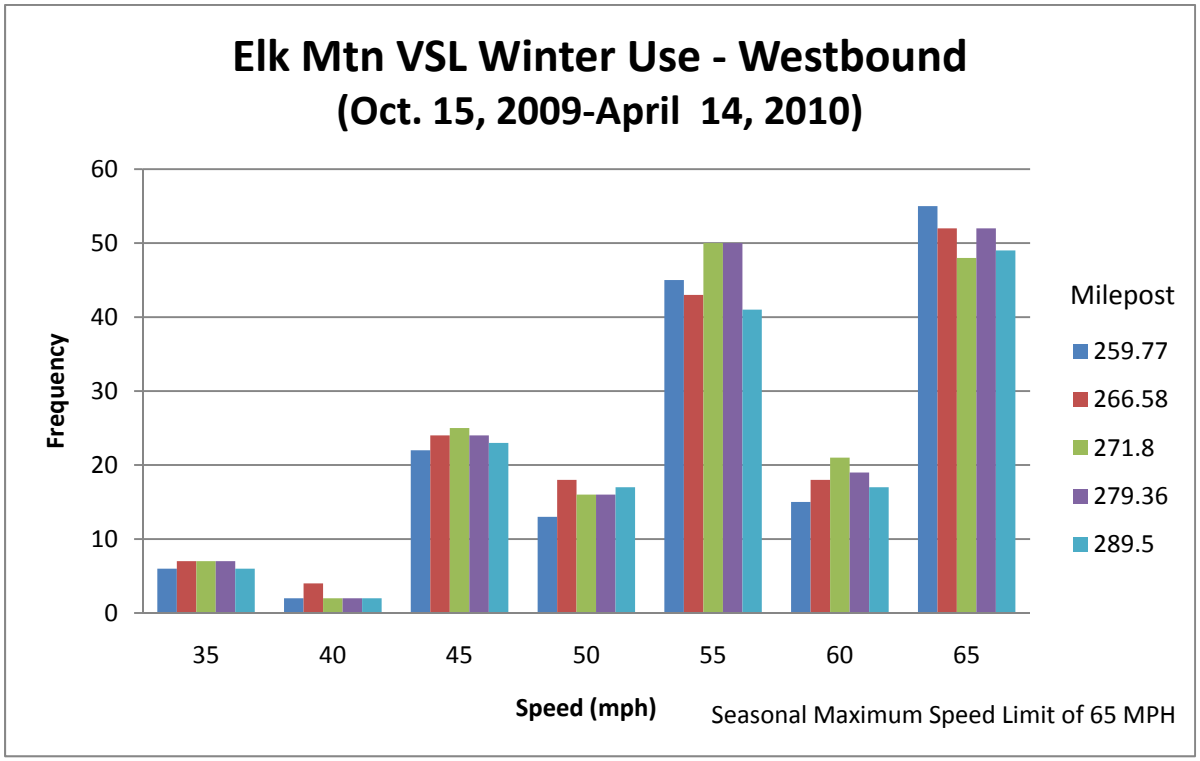

Figure 6-7: Posted Speed vs. Frequency (Winter)

From the speed frequency graphs it was observed that speeds at 55, 45, and 35 mph were implemented more often than at 60, 50 and 40 mph for the winter time periods. Figure 6-8 is an example of the speed versus cumulative duration graphs and shows the overall time that a certain speed was in place at each milepost.

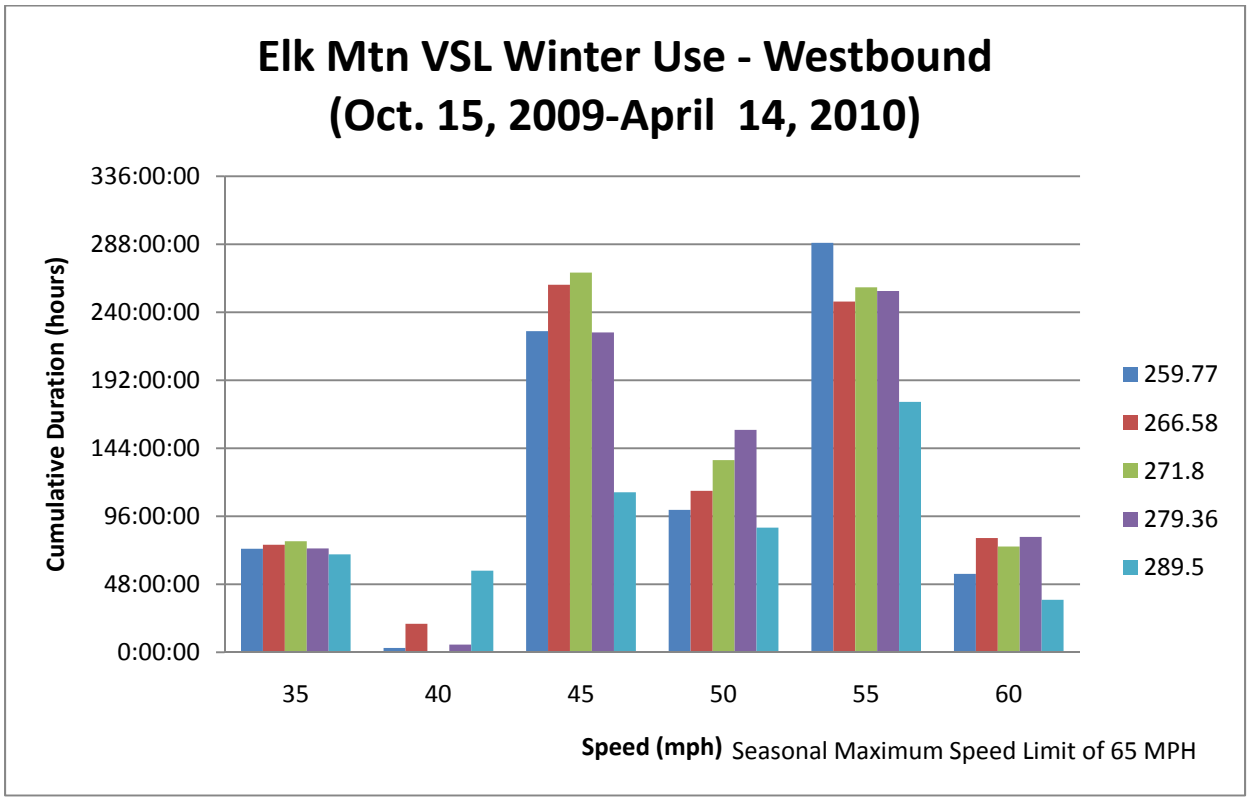

Figure 6-8: Posted Speed versus Cumulative Duration (Winter)

Just as the 75 mph data was omitted from Figure 6-5 for the summer period, the 65 mph data has been omitted from Figure 6-8 for the winter period due the magnitude of the cumulative duration for a speed of 65 mph. Including the 65 mph data in Figure 6-8 would have thrown off the scale. Also, during the winter time period there was a 50 mph posted speed observation that lasted from January 6, 2010 to January 23, 2010 at milepost 271.8. This 50 mph speed did not match the posted speed data for surrounding mileposts and was adjusted since it was unlikely that this speed was left displayed on the VSL

scroll for that time period. To match data from the VSL signs at surrounding mileposts a speed adjustment from 50 mph to 65 mph was added on January 7, 2010 at milepost 271.8.

The 65 mph data for cumulative and average duration can be found in Table 6-3. Figure 6-9 is a representative example of the average duration graphs created.

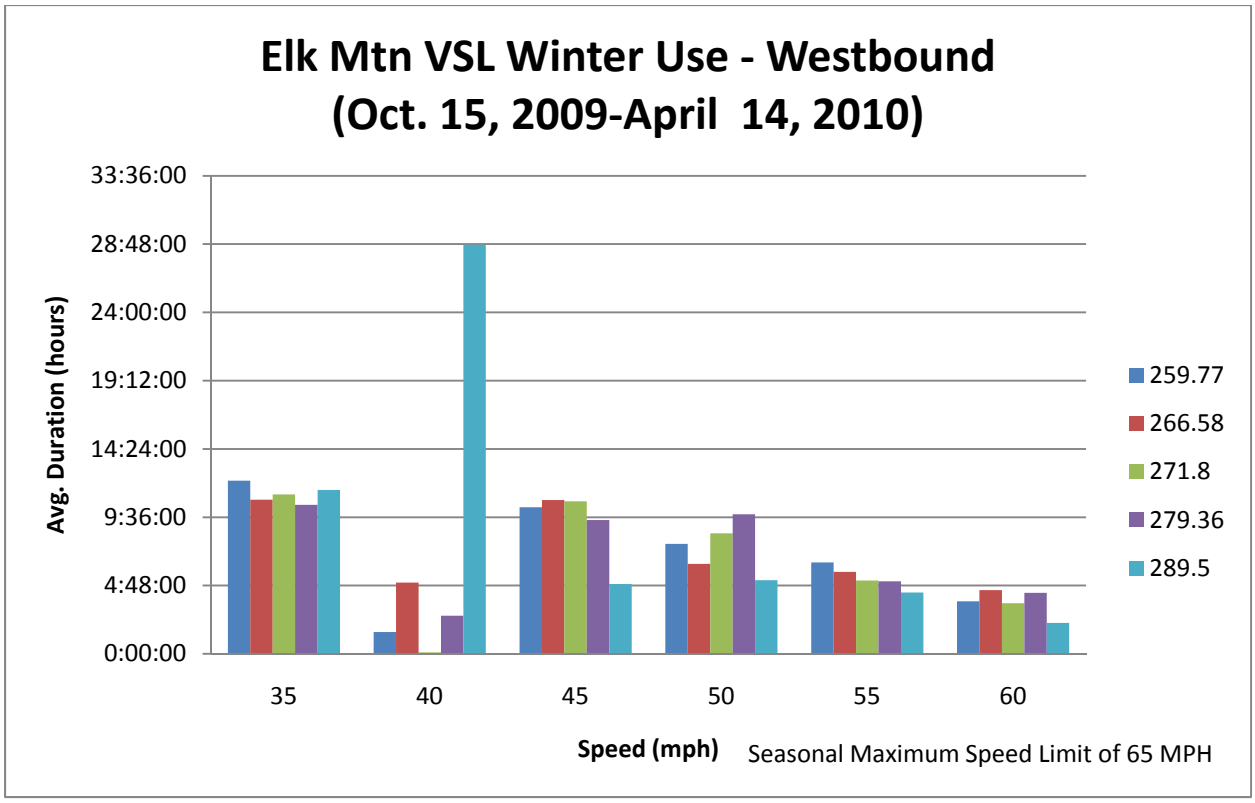

Figure 6-9: Posted Speed versus Average Duration (Winter)

Just as the 65 mph data was omitted from the cumulative duration graph it has been omitted from the average duration graph.

During the winter period from October 15, 2009 to April 14, 2010 four new VSL signs were installed on the corridor. The signs came online on February 3, 2010 at the following mileposts: eastbound 238.8, eastbound 246.7, westbound 246.7, and westbound 254.87. Table 6-4contains all of the data used to create the graphs for the new signs.

Figure 6-10, Figure 6-11, and Figure 6-12 show the graphs created for the westbound direction.

Table 6-4: Use of VSL System (October 15, 2009 through April 14, 2010)

Westbound					Eastbound				
MP 246.7					**MP 246.7**				
Speed	Freq	Cum Duration	Avg. Duration	% of Time Displayed	Speed	Freq	Cum Duration	Avg. Duration	% of Time Displayed
35	2	20:24:26	10:12:13	1.21	35	4	22:06:45	5:31:41	1.31
40	2	0:18:15	0:09:08	0.02	40	2	0:24:48	0:12:24	0.02
45	17	87:42:36	5:09:34	5.19	45	15	94:25:17	6:17:41	5.59
50	9	53:37:28	5:57:30	3.17	50	7	53:21:07	7:37:18	3.16
55	17	85:33:19	5:01:58	5.06	55	21	125:47:39	5:59:25	7.45
60	9	53:04:38	5:53:51	3.14	60	9	51:44:57	5:45:00	3.06
65	49	1388:33:40	28:20:17	82.20	65	29	1341:26:16	46:15:23	79.41
MP 254.87					**MP 238.8**				
Speed	Freq	Cum Duration	Avg. Duration	% of Time Displayed	Speed	Freq	Cum Duration	Avg. Duration	% of Time Displayed
35	3	22:40:49	7:33:36	1.34	35	3	22:14:50	7:24:57	1.32
40	1	0:24:47	0:24:47	0.02	40	1	0:18:29	0:18:29	0.02
45	13	88:11:07	6:47:01	5.22	45	12	70:18:21	5:51:32	4.17
50	9	55:14:56	6:08:20	3.27	50	8	57:35:21	7:11:55	3.41
55	19	112:01:15	5:53:45	6.63	55	17	99:28:18	5:51:05	5.89
60	11	51:07:44	4:38:53	3.02	60	8	47:53:49	5:59:14	2.84
65	27	1360:50:41	50:24:06	80.50	65	27	1389:51:48	51:28:35	82.35

*Note: Signs came online 2/3/2010

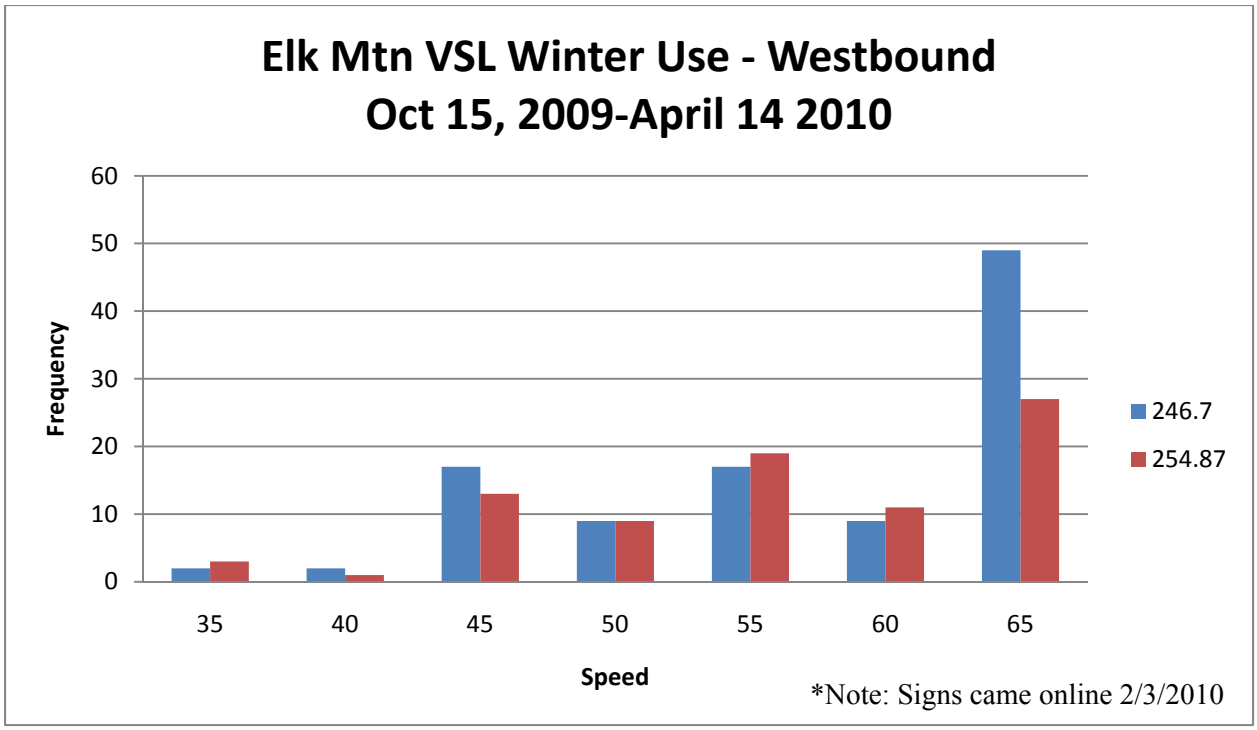

Figure 6-10: Posted Speed versus Frequency (Winter)

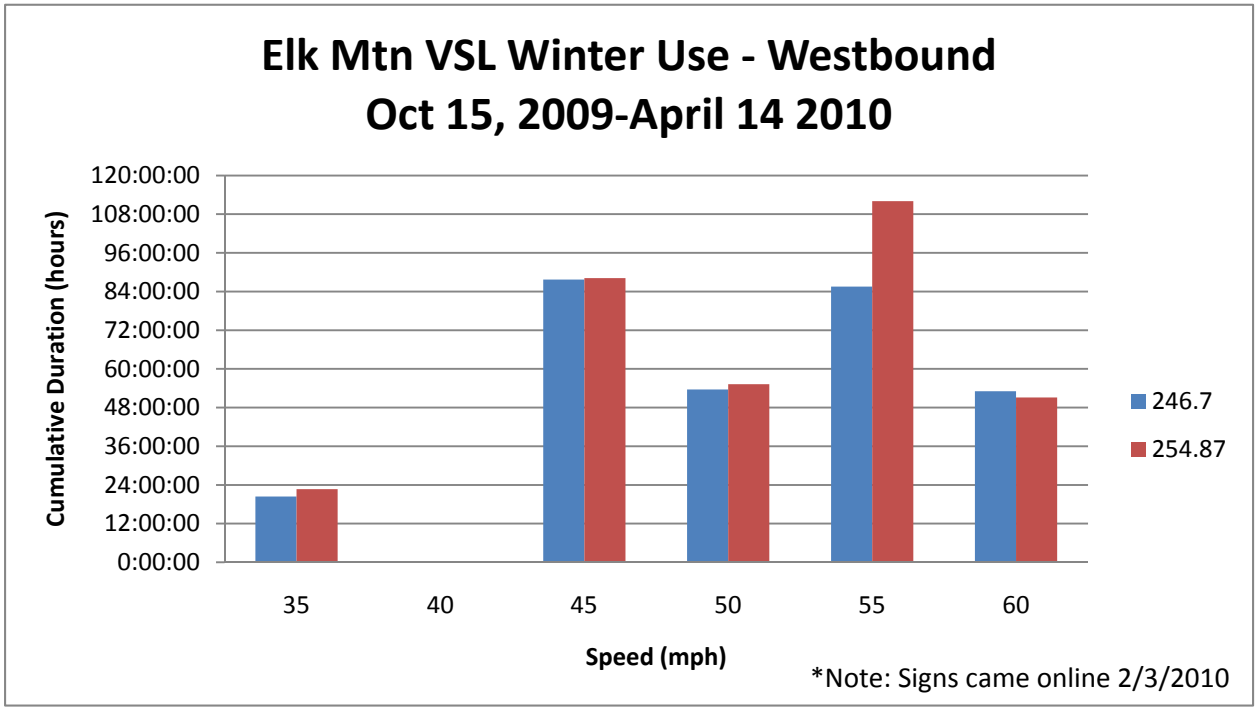

Figure 6-11: Posted Speed versus Cumulative Duration (Winter)

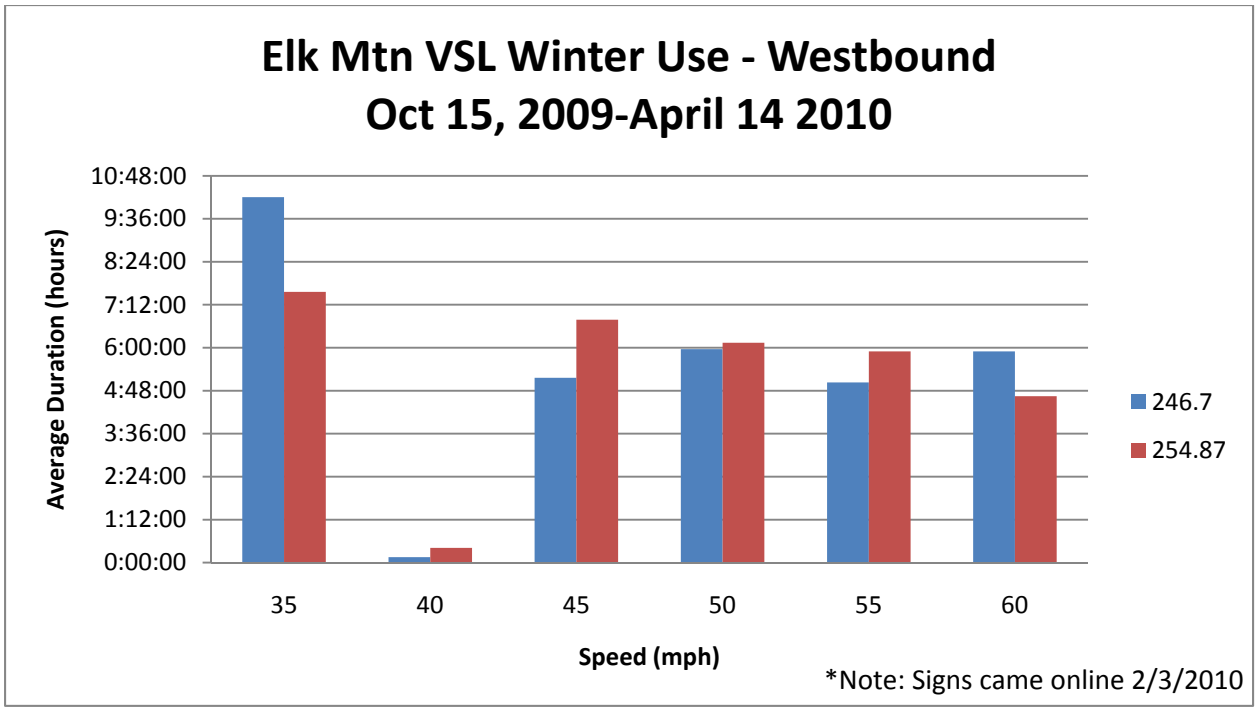

Figure 6-12: Posted Speed versus Average Duration (Winter)

Figure 6-10, Figure 6-11, and Figure 6-12 show similar trends as compared to Figure 6-7, Figure 6-8, and Figure 6-9, which is good since these graphs were all created from the same time period. The speeds of 65, 55, 45, and 35 mph are used much more frequently than 60, 50, and 40 mph. Also, the 65 mph data for cumulative and average duration can be found in Table 6-4 as it was omitted from Figure 6-11and Figure 6-12 just as in previous graphs.

The figures shown previously in this chapter are the graphs created from the westbound data; the remaining graphs for the eastbound direction can be found in Appendix B for all of the storm events. The trends discussed in the preceding text are similar to those seen in the eastbound graphs.

Chapter 7 Data Analysis

Statistical analyses were performed using the speed sensor, weather data, and the variable speed limit database in order to analyze the effects of weather variables and the VSL system on the observed speeds of vehicles. The following chapter will describe the statistical analyses done on the data and the challenges that were met while working with the data sets.

7.1 Baseline Speeds

The "ideal" data obtained under ideal weather and road conditions (as described in Chapter 5) was used to establish baseline speeds along the corridor. Baseline speeds were found for each direction, each lane, for day and night, and by sensor. The baseline speeds allow insight into how drivers travel during favorable conditions. The results will be used to analyze the effectiveness of the VSL system. Because speeds tend to differ by lane, by direction, and can vary based on the time of day, baseline speeds were found based on these criteria. The purpose of this analysis was to show how the speeds differed in each of these categories, not to see how the drivers were reacting along the entire corridor. An analysis was conducted on both the 75 mile per hour data set and the 65 mile per hour data set. This section discusses the results found from each analysis.

75 mile per hour data

The 75 mile per hour data set was collected from September 1, 2008 to September 30, 2008. The data set contained twelve "ideal" days of data (see Chapter 4). Table 7-1 shows the speed sensors that were included in baseline calculations for the 75 mph data set.

Table 7-1: Speed Sensors included in the 75 mph data set

Sensor	Milepost
16	266.4
17	263.5
18	256.25
19	260.2
20	288.3
25	272

When the speed sensor did not register any vehicles passing the location in a five minute period, a zero was recorded for the speed observation. For the baseline speed statistics, all of the zeros were removed from the data. The list below describes the statistics that were calculated.

- *Ave*=Average speed in miles per hour measured during the five minute period.
- *Med*=Median speed in miles per hour measured during the five minute period.
- *Std*=Standard Deviation found from the data.
- *50* = 50th percentile speed in miles per hour of the vehicles that drove past the speed sensor.
- *85* = 85th percentile speed in miles per hour of the vehicles that drove past the speed sensor.

<u>Breakdown by Direction</u>

Table 7-2 shows the analysis of the baseline speeds between the East bound lanes (EB) and the West bound lanes (WB) for the 75 mile per hour data.

Table 7-2: Analysis of baseline speeds by direction of travel

	Ave, 50	Ave, 85	Med, 50	Med, 85	Stdev, 50	Stdev, 85
EB	72.50	79.00	73.00	77.60	6.77	6.77
WB	73.10	78.00	74.00	79.00	9.98	10.27

The average speeds are fairly comparable between EB and WB direction. The WB speeds are slightly higher, with the exception of the Average 85th percentile WB

speed. The median speeds are also comparable with the WB speeds being slightly higher. The standard deviation is higher on the WB direction which means that there is a higher variation in the speeds going WB than there is going EB. The difference in speeds could be due to the geometrics of the roadway.

Breakdown by Lane

Table 7-3 shows the analysis of the baseline speeds between the different lanes. EB left is the passing lane for the EB direction, and EB right is the driving lane for the EB direction. WB left is the passing lane for the WB direction, and WB right is the driving lane for the WB direction.

Table 7-3: Analysis of baseline speeds by lane

	Ave, 50	Ave, 85	Med, 50	Med, 85	Stdev, 50	Stdev, 85
EB left	70.01	75.74	70.00	77.00	6.46	6.48
EB right	74.83	79.36	75.00	80.00	6.91	7.35
WB left	74.62	79.08	74.00	79.00	5.45	5.67
WB right	71.63	76.82	74.00	79.00	12.89	13.33

Heading EB, the speed in the driving lane is faster than the passing lane for both the 50th percentile speed and the 85th percentile speed. Heading WB the speed in the passing lane is higher than the driving lane for both the 50th percentile speed and the 85th percentile speed. The median speeds for the EB lanes follow the same trend as the average speeds. For the WB lanes, the median speeds are the same for the left and right lanes in for both the 50th and 85th percentile speed. The speed variation is higher in both the EB and WB driving lanes than it is in the EB and WB passing lanes. The WB right lane has the highest speed variation.

The speeds in the EB driving lane could be faster due to the winds typically coming from the SW direction. The wind is pushing the drivers, so the speeds could be higher traveling in that lane.

Breakdown by Day/Night

Table 7-4 shows the analysis of the baseline speeds between day and night.

Table 7-4: Analysis of baseline speeds by time of day

	Ave, 50	Ave, 85	Med, 50	Med, 85	Stdev, 50	Stdev, 85
Night	72.77	77.17	73.00	78.00	7.36	7.57
Day	72.77	78.16	74.00	79.00	9.87	10.05

The speeds between day and night are fairly comparable. The 50th percentile speed is exactly the same during the day and night, whereas the 85th percentile speed is slightly higher during the day. The median speeds for both the 50th and 85th percentile speeds are only a mile per hour different. There is more speed variation during the day than at night as can be seen in the standard deviation findings.

Breakdown by Speed Sensor

Table 7-5 shows the breakdown of baseline speeds by speed sensor. Each sensor is located on different terrain, so the speeds could differ by sensor.

Table 7-5: Analysis of baseline speeds by speed sensor

Sensor	Milepost	Ave, 50	Ave, 85	Med, 50	Med, 85	Stdev, 50	Stdev, 85
16	266.4	74.5	79.8	77	82	7.3	7
17	263.5	74.5	78.7	74	79	4.5	4.8
18	256.25	73.4	79.3	73	79	4.1	4
19	260.2	72.6	78.2	73	78	4.1	4.2
20	288.3	74.5	79.6	75	80	5.8	5.9
25	272	66.8	71.6	69	74	13.7	14.3

The speeds along the corridor are comparable. With the exception of Sensor 25, all of the speeds are within a few miles per hour of each other. The median speeds follow

the same trends as the average speeds. Sensor 25 is located next to the Arlington Interchange (MP 272.0) and Sensor 16 is located towards the West Elk Mountain Interchange (MP 266.4). The sensors at the ends of the corridor and also Arlington Interchange have the highest speed variations.

The differences in speeds by speed sensor could be due to the geometrics of the roadway. Even though each speed sensor mile marker is known, the geometrics at each location are unknown. Lower speeds could indicate that the driver is traveling up a grade at that location.

65 mph data

The 65 mile per hour data set was collected from October 22, 2008 to November 19, 2008. On October 15, 2008 WYDOT implemented a seasonal speed limit that lowered the speed limit along the corridor from 75 mph to 65 mph. This seasonal speed limit is in effect until April 15, 2009. This data set consisted of seven days of "ideal" data. Table 7-6 shows the speed sensors that were included in baseline calculations for the 65 mph data set.

Table 7-6: Speed Sensors included in the 65 mph data set

Sensor	Milepost
16	266.4
17	263.5
18	256.25
19	260.2
20	288.3
21	275.4
25	272

Breakdown by direction

Table 7-7 shows the analysis of the baseline speeds between the East bound lanes (EB) and the West bound lanes (WB) for the 65 mile per hour data.

Table 7-7: Analysis of baseline speeds by direction of travel

	Ave, 50	Ave, 85	Med, 50	Med, 85	Stdev, 50	Stdev, 85
EB	68.5	71.7	68.0	71	6.2	6.5
WB	68.7	72.3	69.0	73	7.5	7.5

The speeds are pretty comparable between EB and WB. The WB speeds are slightly higher than the speeds in the EB direction. The median speeds follow the same trend as the average speed. The standard deviation is higher on the WB direction which means that there is a higher variation in the speeds going WB than there is going EB. The seasonal speed limit of 65 mph was displayed during this period. The baseline speeds were calculated during favorable conditions (no moisture, and Wind Gust Speeds less than 45 mph). This table shows that during favorable conditions, drivers are going faster than the seasonal speed limit.

Breakdown by lane

Table 7-8 shows the analysis of the baseline speeds between the different lanes.

Table 7-8: Analysis of baseline speeds by lane

	Ave, 50	Ave, 85	Med, 50	Med, 85	Stdev, 50	Stdev, 85
EB left	71.8	74.2	71.0	74	6.5	7.0
EB right	66.1	69.9	66.0	70.0	4.8	5.5
WB left	70.8	73.9	71.0	74	5.8	6.2
WB right	66.9	71.0	68.0	72	8.2	8.3

The speeds are higher in both the EB and WB passing lanes during the 65 mph data set. The speeds in the EB and WB passing lanes and the driving lanes are still comparable. The drivers are still driving faster than the posted speed limit. The median speeds continue to follow the same trend as the average speed. The variation in speed is

higher in the WB driving lane than it is in the passing lane. In the EB direction, the speed variation is higher in the passing lane than it is in the driving lane. This could be due to the geometrics of the corridor or because the wind comes from the southwest direction and causes the EB drivers to travel faster.

Breakdown by Day/Night

Table 7-9 shows the analysis of baseline speeds by the time of day.

Table 7-9: Analysis of baseline speeds by time of day

	Ave, 50	Ave, 85	Med, 50	Med, 85	Stdev, 50	Stdev, 85
Day	68.5	72.5	69.0	73	7.7	7.6
Night	68.6	71.7	68.0	72	6.1	6.5

The speeds between day and night are pretty comparable. The trend is the same in the median 50th and 85th percentile speeds as well. There is more speed variation during the day than at night as can be seen in the standard deviation findings.

Breakdown by Speed Sensor

Table 7-10 shows the breakdown of baseline speeds by speed sensor. Along the corridor the speed sensors are not all located on flat terrain. Therefore, there could be a difference in the speed that each speed sensor records.

Table 7-10: Analysis of baseline speeds by speed sensor

Sensor	Milepost	Ave, 50	Ave, 85	Med, 50	Med, 85	Stdev, 50	Stdev, 85
16	266.4	70.26	72.35	72	74	6.5	6.47
17	263.5	70.95	70.95	70	70	5.85	5.85
18	256.25	69.36	73.4	69	73	4.66	5.35
19	260.2	69.04	73.13	69	73	4.91	5.54
20	288.3	70.14	74.36	70	75	5.61	6.05
21	275.4	66.62	70.17	66	70	5.63	6.16
25	272	66.52	70.44	67	71	8.73	8.77

The range of speeds in the 50th and 85th percentile findings is less than five miles per hour, so the difference in speed read between the speed sensors is not that high. The

median speeds follow the same trends as the average speeds. Sensor 16 (MP 266.4) and Sensor 25 (MP 272.0) have the highest speed variations. This could be due to the geometrics of the roadway at each sensor.

Comparison of the data from 75 and 65 mph datasets

One of the goals of the Variable Speed Limit system (VSL) is to decrease the speed variation between the vehicles. When there is a large difference in speeds between vehicles, the number of crashes increases. Table 7-11 is a comparison of the EB and WB Baseline speeds between the 65 mph and 75 mph data.

Table 7-11: Comparison of Direction Baseline Speeds

65 mph data set						
Direction	Ave, 50	Ave, 85	Med, 50	Med, 85	Stdev, 50	Stdev, 85
EB	68.5	71.7	68	71	6.2	6.5
WB	68.7	72.3	69	73	7.5	7.5
75 mph data set						
EB	72.5	79	73	77.6	6.8	6.8
WB	73.1	78	74	79	10.0	10.3

As it can be seen from the table, the EB average 50th percentile speeds are slightly slower than the WB speeds. However, in the average 85th percentile speed, the EB direction is slightly higher than the WB speed in the 75 mph data set. In both the 50th percentile and 85th percentile median speeds, the WB speeds are slightly higher than the EB speeds. The WB standard deviations are higher than the EB, especially in the 75 mph data set. This shows that there is more speed variation, as measured by the standard deviations, in the WB lanes than there is in the EB lanes. The speed variation is fairly comparable between the EB speeds in the 65 mph and 75 mph data sets. However, the speed variation is noticeably different from the 75 mph to the 65 mph data sets in the WB

direction. This data shows that reducing the speed limit reduces the speed variation along the corridor.

7.2 Statistical Modeling

Linear regression analysis studies the relation between two or more predictor variables (x_1, x2,…, xi) and the response variable (y). Linear regression estimates the parameters (β_0, $\beta_{1,\ldots,}$ β_i) in the model equation, shown in Equation 3, which are used to predict the values of the response variable.

$$\mathbf{y= \beta_0+\beta_1 x_1+\ldots+ \beta_i x_i} \qquad \textbf{Equation 3}$$

The 85th percentile speed was the response variable for this project when available. This variable was chosen because the 85th percentile speed is generally a better measure of traffic behavior than the 50th percentile speed. For some models the 85th percentile speed was not available due to the TransSuite® software (see Chapter 4). It the 85th percentile speed was not available then the average speed was used as the response variable. The predictor variables for both the 65 and 75 mph data sets were Day_Night, Air Temp, RH, Dewpoint, AvgWindSpeed, GustWindSpeed, SfStatus, and Wind Data. During the 65 mph data set, the visibility variable became available in the RWIS data, so it was included in the modeling of that dataset. The Day_Night variable is a binary variable that was used to account for the time of day, with 0 signifying a nighttime observation and 1 signifying a daytime observation. Daytime observations were identified using the U.S. Naval Observatory's civil twilight records, usually 30 minutes before sunrise to 30 minutes after sunset (United States Naval Observatory, 2007).

The purpose of the statistical modeling during this phase was to complete three modeling tasks. The three tasks were"

- Determine which RWIS variables affect vehicle speeds,
- Determine whether the RWIS station data (at MP 272.5) is accurately depicting weather conditions at each speed sensor, and
- Determine whether the VSL signs are significant in impacting vehicle speeds.

The first two tasks will be described in Section 7.2 and the last task, which was more extensive, will be described in Section 7.3.

In order to determine the baseline speeds, the data was separated into ideal and non-ideal data for analysis. Originally these two data sets were to be combined and used in the statistical modeling, but problems were encountered when trying to import the large datasets from Microsoft Excel data into SAS 9.1. SAS cannot import data directly from Microsoft Excel 2007, so it was necessary to format the files into Microsoft Excel 2003 files. Microsoft Excel 2003 has file size limitations. There can be no more than 64,000 rows of data in a file. The ideal and non-ideal data sets combined contained more than the 64,000 rows of data in a file. Several of the files contained more than 150,000 rows of data. In order to make the analysis possible, the data sets were separated into new spreadsheets that would be small enough to import into SAS 9.1. The smaller spreadsheets that were created will be discussed further in the sections about each modeling task.

After resolving the data importation issues, SAS 9.1 had problems with the way that the data was formatted in Microsoft Excel. As discussed in Chapter 5, the RWIS

data is archived in two different files. The files are then imported into Microsoft Excel using a Visual Basic macro code. When running the RWIS variables through SAS 9.1 either one or all of the variables could not be found. In order to fix the formatting problems, the files were all copied and pasted into the Minitab 15 software program and then copied and re-pasted back into Microsoft Excel. When the numbers were pasted back into Microsoft Excel, they were in a text format that SAS 9.1 still did not recognize. The text cells were converted back into a number format in Microsoft Excel. After this process, the data was in a correct format to run statistical analysis in the SAS 9.1 software. For later analyses it was found that data files could be saved as comma separated files (.csv) from Excel 2007 and directly imported into SAS.

For the initial modeling, the PROC REG command was used to analyze the data using a linear regression model. This analysis gave the broadest statistical analysis of the data that SAS 9.1 can perform. An alpha of 0.1 was used in the initial of modeling for all three tasks. The alpha sets the significance level that is used for the construction of the confidence intervals. An alpha of 0.1 insures a 95% confidence interval for the data. Confidence intervals specify a range in which the parameter is estimated to lie within. For example, a 95% confidence interval covers 95% of the normal distribution curve. The probability of observing a value outside of this area is less than 0.05, or the p-value.

During the initial modeling for all three tasks, the residual versus predicted plots showed that the data had a large number of outliers. The first set of outliers were identified as the zero 85th percentile speeds recorded by the speed sensors. Zeros in the 85th percentile speed column indicate that there were no vehicles that passed the sensor during that five minute period. Since there were no vehicles measured during that period,

the data was treated as missing data when SAS 9.1 ran the models. The visibility column also contained zeros, and these zeros were also creating outliers in the residual verses predicted plots. Zeros in the visibility column would indicate that drivers would not be able to see anything along the road. Even though visibility is sometimes limited, zeros were likely sensor errors and were treated as missing values in the modeling.

Three statistical options were considered in treating the outliers. The first option is to identify the speeds that were causing the outliers and throw the outliers out of the model. For example, if it is concluded that speeds less than 40 and speeds greater than 90 are uncommon speeds along the corridor, the speeds that meet the criterion can be treated as missing data and discarded from the model. The second option was to use indicator variables for speeds that were less than a certain value. For example for speeds less than a certain value, an indicator variable such as 'S', to signify slower speeds, would be given to the data. Commands could then be written so that SAS would recognize the indicator variable and include this in the models. This option was considered uncertain because it was an indicator variable that was based on the response variable in the model. The third option was to use a robust regression model, which will be described in the following paragraphs.

The method of least squares results in distorted fitted models when outliers are left in the data. If data cannot be discarded based on equipment error, sometimes it is hard to determine which cases should be considered an outlier or should be included in the model. In this case, the robust regression model may be better for the data. The robust regression model dampens the influence of outlying cases in order to provide a better fit for the majority of the data. It is a useful model when smooth regression

functions are to be fitted to data that has numerous outlying cases, and the normal distribution for error terms is not appropriate (Kutner, Nachtsheim, & Neter, 2004).

The iteratively reweighted least squares (IRLS) method is one of the most common robust regression procedures. Instead of using weights based on error variance, IRLS robust regression uses weights based on how far an outlying case is, as measured by the residual for that case. The weights are revised with each iteration until a robust fit has been obtained by the statistical software. SAS 9.1 gives the engineer several different methods to dampen the outliers (Kutner, Nachtsheim, & Neter, 2004).

For this phase of the project, it was decided that the best thing to try initially is to throw out specific outliers. In order to see how the outliers were affecting the models, these extreme values had to be treated as missing values within the model. Therefore, threshold speeds had to be set. These were the speeds that seemed realistic to be included in the model and the other speeds would be deemed as outliers. From experience driving on the corridor, it is reasonable that drivers could travel up to twenty miles over the speed limit. Therefore, the 85th percentile speeds that were greater than 100 mph along the corridor were treated as missing values. During poor weather conditions along the corridors, drivers may be impeded by snow plows or queued behind a crash event. It is not uncommon during these conditions for vehicles to not be traveling at speeds determined by the drivers. Therefore, the 85th percentile speeds that were less than 30 mph were treated as missing values in the model.

After eliminating these two groups of outliers, the models were run again using the PROC REG command and an alpha of 0.2. By changing the alpha to 0.2, it made the p-value limit 0.1. An alpha value of 0.2 still gives a 90% confidence interval, which

is still a high standard for the data. Increasing the alpha value ensures that more data falls under the normal distribution and does not fall in one of the two tails. The probability of observing a value inside one of the tails is 0.10.

During this step of the analysis, it was deemed that eliminating the two groups of outliers was not having enough of an impact. The results were very similar to the initial modeling. In many of the models, nothing changed. The only thing that changed between some of the models was that there were more variables included in the final model that excluded the outliers. For example, one of the models where more variables were significant in the model that excluded the outliers was Storm 2.

The comparison of the two models can be seen in Table 7-12. The variables that become significant by changing the alpha to 0.2 and by discarding the outliers are variables that the driver would not react to when they change. WYDOT would not change the VSL based on AirTemp, SfTemp, or the wind directions because they are not variables that the driver can directly observe and adjust their speeds to. Therefore, these variables would be discarded and the model would once again resemble the results found in the initial modeling.

Because the two models are so similar, it was deemed that there could be a problem with the way that SAS 9.1 is discarding the outlier data. Therefore, further analysis should be conducted to see if SAS 9.1 is discarding the correct outlier data.

Table 7-12: Comparison of the two models run

Variable	Models without outliers Coefficient	p-value	Initial Modeling Coefficient	p-value
Intercept	50.60902	<0.0001	50.08072	<0.0001
SfStatus	1.47662	<0.0001	1.45216	<0.0001
SubTemp	0.3668	<0.0001	0.41564	<0.0001
GustWindSpeed	-0.02872	<0.0001	-0.03085	<0.0001
RH	0.01319	0.0031	0.00831	0.0036
Dewpoint	-0.01898	0.0048	-0.02484	<0.0001
Day_Night	1.51052	<0.0001	1.52422	<0.0001
SfTemp	-0.02457	0.0038		
AirTemp	0.05193	0.0039		
wd2	0.78907	0.0457		
wd3	1.27907	0.001		
wd4	1.25299	0.0046		
wd5	1.35631	0.0007		
wd6	0.91201	0.0079		
wd7	1.0524	0.0022		

RWIS Variables and Speed Analysis

The first modeling task was to look at the data that was collected and determine which RWIS variables were significant in affecting driver's speeds. This information will be beneficial to the Traffic Management Center (TMC) because they will know what weather variables are most significant to monitor and will become the focus of the control strategy task discussed in Chapter 9. Since the data had to be split into smaller spreadsheets in order to run in SAS 9.1, this data set was split into different storm events. Each storm event had both ideal (before and after the storm event) and non-ideal (during the storm event) days compiled to see how drivers were reacting in both situations. Two storm events were created for both the 75 mph data set and for the 65 mph data set. Table 7-13 contains information about each storm such as the dates that the storm event spans, the posted speed during that time, and the number of ideal and non-ideal days of data.

Table 7-13: Storm Event Data

Storm	Dates	Posted Speed (mph)	# of ideal days	# of non-ideal days
Storm 1	September 2-6, 2008	75	3	2
Storm 2	September 19-25, 2008	75	3	4
Storm 3	October 28-November 1, 2008	65	2	3
Storm 4	November 13-18, 2008	65	3	3

For the initial model, all predictor variables are included in the model. The p-value indicates the significance of the variable in the model. With an alpha of 0.1, the p-value must be below 0.05 to indicate a significant variable. Since p-values greater than 0.05 are insignificant, they are then removed from the model. The process usually takes multiple iterations because only one variable can be removed from the model per iteration. This is because all the variables influence the model in their own way. When a variable that is insignificant is dropped from the model, other variables could become more or less significant. Therefore, the highest p-value is dropped from the model first, and then another model iteration is run in SAS 9.1. For example, in the initial model for Storm 1, wd6 (Southwest, wind direction) presents as a significant variable. Wd5 (South, wind direction) has the highest p-value, so it is removed from the model in the first iteration. In the next iteration, the p-value for wd6 becomes larger than 0.05 and it becomes insignificant as well. Therefore, it is also dropped from the model and is not significant in the final model.

Table 7-14 shows the results of the initial modeling for the first task for Storm 1. The coefficient column indicates the change in the average speed per unit change of the variable.

Table 7-14: Statistical Results from Storm 1

	Initial Model		Final Model	
Variable	Coefficient	p-value	Coefficient	p-value
Intercept	85.86753	<0.0001	80.57061	<0.0001
SfStatus	1.20988	<0.0001	1.54445	<0.0001
SfTemp	0.03685	<0.0001	0.03795	<0.0001
SubTemp	-0.07994	0.006	-0.07723	0.0045
GustWindSpeed	-0.02892	0.0411	-0.03269	<0.0001
Dewpoint	0.10076	<0.0001	-0.02825	0.0003
Day_Night	1.82396	<0.0001	1.86134	<0.0001
AvgWindSpeed	0.01563	0.4285		
AirTemp	-0.9663	<0.0001		
RH	-0.06629	<0.0001		
wd1	0.39295	0.1515		
wd2	-0.14652	0.4928		
wd3	-0.28485	0.2498		
wd4	0.20492	0.5739		
wd5	0.20492	0.9474		
wd6	-0.67106	0.0016		
wd7	-0.35118	0.0865		

The speeds are higher when the road is dry, the road surface is warm, the temperature is low, the wind speed is low, the air is dry, and when it is daytime (the Day_Night variable is 0 during the night and 1 during the day). From the statistical outcome, the driver's speed increases when it is daylight, by 1.81 miles per hour on average. The SfStatus is 0 when the pavement is wet and 1 when the pavement is dry. Therefore, driver's speeds increase by 1.21 miles per hour when the road is dry. Dewpoint is a temperature, so the magnitude of the coefficient is multiplied by the temperature to get the speed reduction caused by the Dewpoint variable. The variables wd1 through wd7 represent the wind directions that the wind blows along the corridor. From the statistical analysis it can be seen that the wind direction is not significant in impacting driver's speed for this model. The statistical analysis also shows that

AvgWindSpeed is not a significant variable in the model. This could be because GustWindSpeeds are more sudden and cause more impact on driver's speed than the AvgWindSpeed. The negative coefficients for AirTemp and SubTemp (Subsurface Temperature) are surprising; this result is counter intuitive since it indicates that speeds increase as temperatures decrease.

The model for Storm 2 is very similar to Storm 1. None of the WindDirection variables were found to be significant. The only difference was RH was found to be significant in Storm 2 but not 1. Table 7-15 shows the statistical results from Storm 2. The magnitudes of the variables are similar for the most part. There are several variables where the coefficient becomes negative, but the magnitude remains the same. For this model the AirTemp variable becomes insignificant and the subsurface temperature is significant and has a more logical positive coefficient than the Storm 1 model.

Table 7-15: Statistical Results for Storm 2

	Initial Model		Final Model	
Variable	Coefficient	p-value	Coefficient	p-value
Intercept	50.28397	<0.0001	50.08072	<0.0001
SfStatus	1.46749	<0.0001	1.45216	<0.0001
SfTemp	-0.02398	0.0052	0.03795	<0.0001
SubTemp	0.36733	<0.0001	0.41564	<0.0001
GustWindSpeed	-0.03562	0.0295	-0.03085	<0.0001
Dewpoint	-0.01906	0.0046	-0.2484	<0.0001
Day_Night	1.51037	<0.0001	1.52422	<0.0001
RH	0.01322	0.0031	0.00831	0.0036
AvgWindSpeed	0.01002	0.6429		
AirTemp	0.05155	0.0042		
wd1	0.92166	0.1771		
wd2	1.08485	0.0185		
wd3	1.57588	0.0006		
wd4	1.56617	0.0017		
wd5	1.66759	0.0003		
wd6	1.20862	0.0036		
wd7	1.34766	0.0012		

The 65 mph data contained the Vis1 column, which indicated the visibility as measured at the RWIS station. Table 7-16 shows the results of modeling Storm 3 which contained the Vis1 variable. The visibility variable is in feet. From the Table, it can be seen that Visibility has a very low estimated coefficient but it must be noted that the typical measurement of visibility (measured in feet) is quite large. Even though the RH variable became significant in this model, the magnitude of the coefficient is low. If the RH value was 100%, vehicle speeds would change 6.1 mph. In this model, the GustWindSpeed is not a significant variablebut AvgWindSpeed is significant. This is likely due to the nature of wind events in the winter months as opposed to the summer storms for the first two models.

Table 7-16: Statistical Results from Storm 3

	Initial Model		Final Model	
Variable	Coefficient	p-value	Coefficient	p-value
Intercept	67.53146	<0.0001	65.05848	<0.0001
Day_Night	0.972	<0.0001	0.978487	<0.0001
SfTemp	0.08378	<0.0001	0.8418	<0.0001
SubTemp	0.18278	<0.0001	0.18882	<0.0001
AirTemp	-0.09	<0.0001	-0.08932	<0.0001
RH	0.06087	<0.0001	0.06066	<0.0001
Dewpoint	-0.12059	<0.0001	-0.11886	<0.0001
Vis1	-0.00006193	<0.0001	-0.00006154	<0.0001
AvgWindSpeed	-0.03335	0.1814	-0.05198	<0.0001
GustWindSpeed	-0.01506	0.4578		
SfStatus	-1.28685	0.169		
wd1	0.02407	0.9945		
wd2	1.64375	0.5182		
wd4	-0.39028	0.878		
wd5	2.40668	0.2096		
wd6	-0.80202	0.3787		
wd7	-0.73025	0.4223		

Storms 3 and 4 included the same variables in the models but the outcomes were quite different. The final model of Storm 4 includes three wind direction variables and the SfStatus variable. In Storm 4, two of the WindDirection coefficients have a magnitude greater than 15. Table 7-17 shows the results of modeling Storm 4.

Table 7-17: Statistical Results for Storm 4

	Initial Model		Final Model	
Variable	Coefficient	p-value	Coefficient	p-value
Intercept	65.9648	<0.0001	62.13351	<0.0001
SfStatus	2.01306	<0.0001	1.28603	<0.0001
SubTemp	0.1613	<0.0001	0.30562	<0.0001
Day_Night	1.06579	<0.0001	2.74181	<0.0001
RH	-0.11047	<0.0001	-0.1349	<0.0001
Vis 1	0.00003817	<0.0001	0.00004437	<0.0001
wd1	-15.31515	<0.0001	-15.80441	<0.0001
wd2	-19.57423	<0.0001	-20.10388	<0.0001
wd3	-0.19902	0.0119	0.43225	<0.0001
AvgWindSpeed	0.03599	0.0062		
AirTemp	-0.06301	<0.0001		
GustWindSpeed	-0.02767	0.0064		
Dewpoint	0.00393	0.0807		
SfTemp	0.1613	<0.0001		

From all the models it seems that, while the results are fairly similar, each storm event has differences. The magnitudes of each variable are fairly consistent throughout all of the storms. The only variable magnitudes that do not correspond with the other storms are the wind direction coefficients for wd1 and wd2 in Storm 4.

In each storm event, different variables are impacting driver's speeds differently. The variables described in the following paragraphs were significant in at least three out of the four models. These are the variables which are evident to drivers and would change their speeds if they thought the conditions were dangerous. Variables such as RH

and AirTemp, even though they were significant in some of the models, are not likely variables for drivers to react to when encountered.

Whether it is daytime or nighttime has an impact on driver's speeds. Drivers drive faster during the day than they do at night. SfStatus was significant in three out of the four models. Drivers speeds are faster when the surface is dry than when there is moisture on the road. Visibility was significant in both Storms 3 and 4. Even though it does not impact the driver's speed very much, drivers are still reacting if the visibility changes. Wind speed, gust speed in two models and average speed in one, is also a factor that impacts driver's speeds. Storm 4 was the only event in which neither WindGustSpeed or AvgWindSpeed were significant. In all other storm events, either one or the other is significant.

RWIS significance

The second modeling task was to look at each individual speed sensor to see how the single RWIS station was describing the atmospheric and surface conditions at each speed sensor location. The corridor is 52 miles long and the weather conditions can change drastically over the length of the corridor. Therefore, determining how accurate the RWIS is describing the speeds is important. For this task, the 65 mph data set had the most functioning sensors, so the data from this set was used. During the 65 mph data set, eight of the speed sensors were functioning. The list of working sensors and their locations can be seen in Table 7-18. The speed sensor at Arlington was used as control sensor because the RWIS is located at Arlington as well. The first step was to see how significant the weather variables are at the Arlington sensor, and then compare the other speed sensors and their significant variables to the Arlington sensor.

Table 7-18: Sensors used in RWIS modeling

Sensor ID	MP location
16	266.4
17	263.5
18	256.2
19	260.2
20	288.3
21	275.4
24	282.5
25	272

Table 7-19 shows the statistical analysis for the Arlington speed sensor (MP 272), which is the closest speed sensor to the RWIS station.

Table 7-19: Statistical Modeling of Arlington Speed Sensor

	Initial Model		Final Model	
Variable	Coefficient	p-value	Coefficient	p-value
Intercept	8.48373	0.4111	0.48236	0.9395
Day_Night	-1.65825	0.0006	-1.82424	<0.0001
SfTemp	0.06592	0.0408	0.06357	<0.0001
Dewpoint	-0.14285	0.1895	-0.06411	0.0807
SubTemp	1.22107	<0.0001	1.26315	<0.0001
Vis1	0.00015880	0.0040	0.00017446	0.0004
RH	0.07101	0.5347		
GustWindSpeed	-0.02266	0.7426		
SfStatus	-2.75873	0.1977		
AirTemp	0.02561	0.8362		
AvgWindSpeed	-0.02227	0.7903		
wd1	-4.22724	0.1649		
wd2	-4.16374	0.1730		

At this location only five of the twelve RWIS variables are significant. The Day_Night had the most impact at this sensor where Day values had a negative coefficient of -1.82. This means that during the day, the speeds decreased by almost two miles an hour at this station. The sample size of the data set did not have as many observations as earlier sets. This could explain the counterintuitive Day_Night

coefficient. The other coefficient magnitudes are similar to the modeling completed during the RWIS Variables and Speed Analysis section.

Table 7-20 shows the comparison of all of the sensors along the corridor to the control speed sensor. The number of variables that match the control sensor indicates the number of variables in the final model of each sensor that matched up with the significant variables in the final model of the control sensor.

Table 7-20: Comparison of All Sensors to Control Sensor

Sensor	# of Variables that match control sensor	# of Variables that don't match control sensor
16	2	2
17	4	3
18	4	5
19	3	2
20	5	1
21	4	2
24	4	3

Sensor 16 is the sensor with the least number of variables that match the control sensor. This speed sensor is located at the west end of the corridor while the RWIS station is located in the middle of the corridor. Overall, the RWIS station does a reasonable job at describing the conditions along the corridor. Just as every storm event is entirely different, storm events hit different locations in varying degrees. In Sensors 16 through 19 WindGustSpeed was not a significant variable. Even though the RWIS station does a reasonable job at describing the conditions along the corridor, it would be beneficial to have more RWIS stations along the corridor so that the weather conditions at each sensor are more accurately defined.

WYDOT has installed additional RWIS (see Chapter 4) along the corridor in 2010 but at the time of this report the new RWIS are still being tested. All individual sensor modeling can be found in the Appendix C.

The process discussed in this section will be used to link roadway segments to different RWIS stations. Therefore, the speed sensor data will be appended to the RWIS station that is closest to that sensor. This will provide more accurate data to be analyzed in the future.

7.3 VSL Sign Significance Models

The third modeling task for this phase was determining whether the VSL signs are impacting driver's speeds. The data set for the VSL sign significance modeling task was comprised of the VSL database, the RWIS data, as well as speed data retrieved from the TransSuite® Software for two data periods: one in the first few months the VSL was in operation and another for a period after the VSL was operational for over 8 months.

For the first model in this task SAS 9.1 was used to test the significance of the variables using the dataset that merged the Speed, VSL sign and RWIS data. The merged dataset went through quality checks and then was split into two files based on directions (EB and WB). The variables which were used in the analysis were dependent on the availability of the information from the RWIS. For sake of analysis the RWIS variable surface status (SfStatus) was converted into binary form, 1 was used to indicate if the road conditions is dry and 0 was used for wet conditions. In a similar way for another RWIS variable precipitation type (PrecipType) was converted into binary format where 0 was used if the perception type is snow else 1.

A linear regression model was estimated using SAS 9.1's PROC REG command. A two-tailed alpha of 0.1 was used that sets the significance level for the confidence intervals. A two-tailed alpha of 0.1 insures a 95% confidence interval for the data. The probability of observing a value outside of this area, or the p-value, is less than 0.05.

In the later tasks to resolve the file size and outliers issues, SAS 9.2 was used to perform the analysis. Using the SAS 9.2's procedure PROC ROBUSTREG outliers issue was solved. The analyses are described further in the following sections of this chapter.

Initial VSL Implementation

For the initial VSL period data was collected and merged for the period from February 17, 2009 to April 14, 2009. In order to see if the VSL signs are impacting the driver speeds, the speed limits that were placed on the EB and the WB VSL signs were added as variables in the merged speed and RWIS datasets. The EB variable is the speed limit that the driver reads on the VSL sign that is upstream and closest to that speed sensor.

Analysis was completed on each of the six speed sensors that had communication with the TMC during the analysis period. During this time period, the precipitation rate (PrecipRate) variable became available on the RWIS. Prior to this time period the RWIS just recorded zeros for this variable due to a sensor malfunction.

SAS 9.1's PROC REG command was used with the alpha value of 0.2 in the analysis of this data. The same statistical procedure used in the statistical analyses described in the previous section of removing insignificant variables one at a time until all variables in the final model have a p-value of 0.05 or less. The final model of the statistical test results are shown in Table 7-21(westbound) and Table 7-22(eastbound).

Table 7-21: Final Model Results for Initial Westbound VSL Sign Significance (Feb 17 to April 14, 2009)

Variable	West Bound					
Speed Sensor	**MP 288.30**	**MP 275.40***	**MP 266.40**	**MP 263.50**	**MP 260.30**	**MP 256.20**
	Coef	Coef	Coef	Coef	Coef	Coef
Intercept	34.20	21.32	27.65	30.00	26.96	17.40
West Bound	0.500	0.525	0.603	0.572	0.616	0.745
Day & Night	1.165	2.393	1.534	1.210	1.275	1.298
Surface Status	1.546	4.361	0.036	1.391	1.384	1.498
Surface Temp	0.048	0.031	-	0.027	0.030	0.043
Sub Temp	-0.069	0.283	-	-0.082	-	0.021
Chem Factor	0.041	0.081	-0.034	-	-	-
Precip Rate	-	-	-	-	-	-5.145
Air Temp	-	-0.071	0.055	0.034	0.015	-
RH	0.029	-	-	-	-	-0.009
Dewpoint	-0.059	0.026	-0.014	-	-0.012	-
Avg Wind Speed	-0.041	-0.170	-	-0.089	-0.070	-
Gust Wind Speed	-	-	-0.067	-	-	-0.060
Wind1(N)	-	-	-2.429	-	-	-
Wind2(NE)	-	1.799	1.470	-	-0.982	-1.015
Wind3(E)	-1.267	-	1.686	-	-	-
Wind4(SE)	-	-	-	-	-	-2.643
Wind5(S)	-	-	-	-	-	-
Wind6(SW)	-	0.592	-	-	0.330	0.198
Wind7(W)	-	-	0.335	-	-	-
Visibility	0.00003	-	0.0001	0.0001	-	-

* Data available from 3/10-4/6 only for MP 275.40

Table 7-22: Final Model Results for Initial Eastbound VSL Sign Significance (Feb 17 to April 14, 2009)

Variable	East Bound					
Speed Sensor	**MP 256.30**	**MP 260.30**	**MP 263.05**	**MP 266.40**	**MP 275.40***	**MP 288.30**
	Coef	**Coef**	**Coef**	**Coef**	**Coef**	**Coef**
Intercept	17.94	28.03	31.61	31.37	30.21	34.539
East Bound	0.744	0.614	0.54022	0.552	0.50279	0.473
Day & Night	1.305	1.236	0.97009	1.290	2.21921	1.003
Surface Status	1.268	1.226	2.00938	-	3.08274	1.836
Surface Temp	0.043	0.031	0.03492	0.054	-	0.055
Sub Temp	0.017	-	-0.09033	-	-	0.047
Chem Factor	-	-	-	-0.051	0.04662	0.059

PrecipRate	-5.488	-	-	-	-50.17623	-
Air Temp	-	-	0.02444	0.033	0.0716	-
RH	-0.010	-0.010	-	-	-	0.033
Dewpoint	-	-	0.023	-	0.03511	-0.068
Avg Wind Speed	-	-0.070	-0.071	-	-0.1883	-0.036
Gust Wind Speed	-0.059	-	-	-0.063	-	-
Wind 1 (N)	-	-	-	-2.355	-	-
Wind 2 (NE)	-0.99952	-0.797	-	-	1.56324	-
Wind 3 (E)	-	-	-	-	-	-1.364
Wind 4 (SE)	-2.61949	-	-	-	-	-
Wind 5 (S)	-	-	-	-	-	-
Wind 6 (SW)	0.1959	0.307	-	-	0.94431	-
Wind 7 (W)	-	-	-	-	-	-
Visibility	-	-	0.00004	0.00004	-	0.00002

* Data available from 3/10-4/6 only for MP 275.40

The complete results for both the initial and final models for each milepost can be found in Appendix D.

Even though the model for each milepost is slightly different, the results indicate that the Variable Speed Limit signs are impacting driver speeds. The coefficients for the eastbound (EB) and westbound (WB) sign variables, shown in Table 7-21 and Table 7-22 range from 0.47 to 0.75. This indicates that when the speed limit is reduced by one mile per hour, there is between a 0.47 and 0.75 mile per hour reduction in driver's speeds. The magnitude of the coefficients indicate that there is more compliance with the speed that is posted on the signs on the west end of the corridor (i.e. closer to the town of Rawlins). The drivers are still modifying their speeds when they pass the signs on the east end of the corridor (i.e. closest to Laramie) as well, but the magnitude of the coefficient is not as high.

The Day_Night and surface status (SfStatus) variables remain significant variables in the models. Their binary value is multiplied by the coefficient to give an

impact on drivers speed with respect to that variable. Each of the other variables had a numeric reading from the RWIS that is multiplied by the coefficient in the table to give the change in drivers speed. For example, if the Gust Wind Speed has a -0.0586 coefficient and the RWIS reading is 45 mph, drivers slow down by 2.64 miles per hour.

The precipitation rate became a significant variable in three of the twelve models. Because the evidence is not consistent as to whether the precipitation rate is a significant variable, it is recommended that more statistical analysis be conducted during the next phase of the project to figure whether this variable should be included in the final decision support system.

The other variables that were significant were the same variables that were found in the RWIS modeling effort using the speed and RWIS variables modeling described in the previous section. Day and night, surface status, wind speed, and visibility were common variables in the final modeling of each speed sensor.

VSL Sign Significance for Winter 2009

Due to size and outliers issue with the SAS 9.1 a new version of SAS (SAS 9.2) was used in the later tasks of the project. For the winter time period between October 15, 2009 and December 15, 2009 when the seasonal speed limit was 65 mph, additional statistical tests on the VSL sign significance were performed. To deal with the outliers issues a Robust Regression Analysis was conducted.

There were problems with the RWIS data this time period so several days from each month had missing weather data. A statistical analysis was performed on the remaining data. After completing quality checks and the merging process all the Excel files were converted into Comma Separated Value files (CSV) and imported into SAS

9.2. The procedure PROC ROBUSTREG was run to determine the significance of RWIS and posted speed limit variables in EB and WB directions. The same statistical procedure for eliminating insignificant variables that was used in the analysis described in the previous section was used for this analysis (95% confidence, p-value < 0.05). The final results of the statistical models for the eastbound and westbound directions are shown in Table 7-23 and Table 7-24. Complete results for the initial and final models can be found in Appendix D.

Table 7-23: Final Model Results for Winter 2009 Eastbound VSL Sign Significance

	EAST BOUND							
MILE POSTS	**256.25**	**260.2**	**263.5**	**266.4**	**268.1**	**278.13**	**282.5**	**288.3**
Variable								
Intercept	34.204	22.850	20.361	17.440	28.397	19.819	16.252	27.458
Day/Night	1.034	1.180	1.749	1.744	2.581	1.180	1.517	0.866
EB	0.593	0.649	0.712	0.719	0.669	0.799	0.799	0.716
SfStatus	0.872	0.916	0.725	1.292	0.644	0.660	0.692	0.206
SfTemp	0.068	0.085	0.025	0.144	0.034	0.062	0.052	0.036
SubTemp	-0.089	-0.014	0.124	-0.067	-0.015	-0.041	-	-
AirTemp	-0.104	-0.088	-0.042	-0.130	-0.104	-0.046	-0.055	-0.089
RH	-0.037	-0.020	-	-0.042	-0.067	-0.008	-0.021	-0.048
Dewpoint	0.074	0.039	-0.045	0.079	0.096	0.034	0.028	0.069
AvgWindSpeed	0.010	0.038	0.044	0.023	0.018	0.030	0.048	0.045
GustWindSpeed	-	-0.084	-0.088	-0.036	-0.086	-0.041	-0.076	-0.056
wd1	-	-	-	-0.636	-	-0.738	-	-
wd2	-0.811	-0.937	-0.331	-1.317	-0.435	-1.507	-0.924	-0.747
wd3	0.446	0.291	-	-1.402	0.632	-0.928	-0.860	-0.539
wd4	-0.584	-0.751	-	-1.985	-0.569	-1.271	-1.467	-
wd5	-	-	-	-	-	-0.863	-0.856	-0.658
wd6	-0.118	-	-	-	-	-0.615	-0.301	-
wd7	-	-	0.270	-	-	-0.322	-0.302	0.156
PrecipType	1.483	1.674	1.443	2.269	2.574	1.524	0.923	1.244
Visibility	0.0001	0.0001	-0.0001	-	0.0001	0.0001	0.0001	0.0001

Table 7-24: Final Model Results for Winter 2009 Westbound VSL Sign Significance

	WEST BOUND							
MILE POSTS	**256.25**	**260.2**	**263.5**	**266.4**	**268.1**	**278.13**	**282.5**	**288.3**
Variable								
Intercept	28.789	25.739	17.009	13.707	16.697	25.209	25.129	32.312
Day/Night	1.746	1.654	0.895	1.636	1.370	2.115	2.072	1.816
WB	0.586	0.668	0.830	0.855	0.776	0.632	0.633	0.541
SfStatus	0.681	0.335	0.564	1.063	1.497	0.707	0.845	1.007
SfTemp	0.044	0.040	0.106	0.014	0.120	0.025	0.028	0.020
SubTemp	0.064	0.079	0.024	0.046	-0.046	-	0.037	0.035
AirTemp	-0.069	-0.100	-0.158	-0.032	-0.122	-	-0.047	-0.068
RH	-0.016	-0.040	-0.030	-0.037	-0.030	-0.025	-0.037	-0.035
Dewpoint	-	0.032	0.028	0.053	0.055	0.022	0.050	0.058
AvgWindSpeed	0.054	0.025	-	0.042	-	-	0.026	0.033
GustWindSpeed	-0.089	-0.045	-	-0.114	-0.021	-0.085	-0.033	-0.037
wd1	-	-	-	-	-0.952	-	-	-
wd2	-0.747	-0.370	-1.590	-0.343	-1.657	-	-0.319	-0.589
wd3	0.575	0.764	-0.546	-	-1.599	1.249	-0.354	-0.278
wd4	-0.704	-	-	-	-1.517	-	-0.622	-0.956
wd5	-	-	-0.644	-	-0.728	-	-	-
wd6	-	-	-0.469	0.275	-0.386	0.705	-	0.286
wd7	-	-0.126	-	0.386	-0.209	0.468	-	0.241
PrecipType	1.628	1.850	0.868	1.391	2.267	1.428	1.015	1.159
Visibility	-	0.0001	-	0.0001	-0.0001	-	-	0.0001

The results indicated that the posted speed limits on the VSL signs continued to have an impact on observed vehicle speeds. The coefficients for eastbound (EB) and westbound (WB) sign variables, shown in Table 7-23 and Table 7-24, range from 0.54 to 0.86. This indicates that a speed reduction on the VSL signs of 10 mph would result in between a 5.4 and 8.6 mph observed speed reduction even when natural slowing due to weather variables are factored in. These results are slightly higher (improved) from the results for the initial VSL implementation period, which could indicate more acceptance of the VSL system.

Statistical Significance Individual Speeds

Individual speed data was collected from December 1st to December 2nd 2009 for the mileposts 256.25, 273.15 and 289.5. Individual speed data can provide a clearer picture on the relationship between speeds, weather, and VSL signs since you can see the response of individual vehicles to conditions. The individual speed data was merged with RWIS data and VSL sign data. Using SAS 9.2's ROBUSTREG procedure the statistical analysis was done using the same procedure for removing insignificant variables and confidence levels as the previous tasks. The final model results of both the eastbound and westbound directions are shown in Table 7-25 and Table 7-26. Full results for both the initial and final models for all mileposts can be found in Appendix D.

Table 7-25: Final Model Summary of VSL Sign Significance on Individual Data (Eastbound, All MP)

	EAST BOUND		
MILE POSTS	**256.25**	**273.15**	**289.5**
Variable	**Coefficient**	**Coefficient**	**Coefficient**
Intercept	51.8746	48.4331	87.098
EB	0.3843	0.6428	0.4365
SfStatus	1.4017	1.8104	3.4959
SfTemp	-	-	-
SubTemp	-0.398	-0.48	-1.5687
AirTemp	0.2369	-0.4913	0.3922

RH	-	-0.1593	-
Dewpoint	-	0.6555	0.1352
AvgWindSpeed	-	-	-
GustWindSpeed	-0.1609	-	-
wd1	-	-	-1.4362
wd2	-1.948	-3.1845	-3.1759
wd3	-4.0352	-4.9356	-
wd4	3.2238	-	-
wd5	-	-	-
wd6	0.9295	-	-
wd7	-	-	-
PrecipType	3.0402	3.2105	3.7751
Visibility	-	0.0003	-0.0004

Table 7-26: Final Model Summary of VSL Sign Significance on Individual Data (Westbound, All MP)

	WEST BOUND		
MILE POSTS	**256.25**	**273.85**	**289.5**
Variable	**Coefficient**	**Coefficient**	**Coefficient**
Intercept	43.8196	51.0752	77.6698
WB	0.3446	0.5848	0.4732
SfStatus	1.5918	0.8683	1.6248
SfTemp	0.0757	-	0.0963
SubTemp	-	-	-1.4558
AirTemp	0.2784	-0.3573	0.2435
RH	-0.0385	-0.2688	-
Dewpoint	-	0.6463	0.279
AvgWindSpeed	-	-	-
GustWindSpeed	-0.3298	-0.1235	-
wd1	-	-	-1.4631
wd2	-3.3485	-5.2745	-1.997
wd3	-5.0602	-2.73	1.9078
wd4	-	-	-
wd5	-	-	-
wd6	0.9277	1.0885	-
wd7	1.0422	0.5023	-
PrecipType	4.4955	2.998	3.3779
Visibility	-0.0003	-0.0002	-0.0001

The coefficient of the variables EB and WB are in the range of 0.34 to 0.64 suggesting that speed compliance is lower than that indicated in the previous two modeling tasks. The RWIS variable precipitation type has significant impact on speeds the coefficients are varies from 2.998 to 4.495 so that indicates that when there is snow or rain, speeds of the vehicles are dropping by 3-4 mph. The wind directions suggests that if the wind is from particular direction then there might be a chance of snow but there was no significant impact of average wind speed and gusty wind speeds on drivers speed.

The results from this model represent speed observation for only one storm event as opposed to the previous models which were based on data for several storms.

7.4 Statistical Modeling Summary

The baseline speed statistics showed that the seasonal speed limit was reducing the speed variation along the corridor. It also showed the speeds that drivers were traveling under ideal conditions. During the 75 mph data set, the average 85th percentile speed was within five miles of the posted speed limit. During the 65 mph data set, the average 85th percentile speed was higher than 70 mph indicating poor speed compliance to the seasonal speed limit.

Statistical modeling showed that the RWIS station is depicting the conditions along the corridor fairly well. Sensor 16 had the fewest variables in common with the control sensor located at Arlington, but overall the speed sensors contained most of the same significant variables. Even though the one RWIS station is depicting the conditions along the corridor, it would be beneficial to have more RWIS stations so that each speed sensor is matched with weather data that is occurring at that location.

The final statistical modeling task showed that the VSL signs are having an impact on driver's speeds. This first model use data that was collected right after the signs were installed so there could have been some initial resistance from drivers to follow the posted speed limit. The second model for winter 2009 showed a slight improvement to the VSL sign impacts on reducing speeds. On the other hand the model using individual speed observations from a single storm in December of 2009 showed a substantial drop in the VSL sign impacts.

Chapter 8 Analysis of Individual Vehicle Speed Observations

The speed data analysis from Chapter 7 used the binned data from the speed sensor that did not allow for the differences between vehicle types to be analyzed. For this Chapter, Individual Speed Observation data was used that allowed for additional analyses to be performed. Data from three mileposts (256.25, 273.15, and 289.5) was obtained for three different storm events. Individual data logs were created by the WYDOT TMC. The data collected was of individual vehicle observations for storms occurring: December 1-2, 2009; February 3-4, 2010; and March 18-21, 2010. The VSL was used to reduce speeds during the storm events that occurred in December and March. Data was also obtained for one ideal period when the seasonal speed limit was removed from June 4-6, 2010. Collecting individual data requires sensors to be taken off-line from the program that runs the TMC speed map and therefore data from only three sensors was collected for limited time durations. The sensors selected to get observations from are at the beginning, middle, and end of the corridor. The original binned data does not give 85th percentile speeds; nor does it separate cars and trucks. The individual data obtained can be separated into cars and trucks and the 85th percentile speeds can be calculated. The data for each storm event was converted into Excel files and analyzed using SAS and Excel.

The 85th percentile speeds were calculated for each milepost and storm event for both cars and trucks, which were separated using vehicle classifications given in the original data sets. Vehicles are considered to be cars if their length is less than 20 feet. Vehicles are considered to be trucks if their length is greater than 20 feet. The 85th percentile speeds were then grouped into 5 and 15 minute averages and graphed. The 15 minute average graphs were created to help reduce the “noise” seen in the 5 minute

average graph so that trends could be better observed. Also, the standard deviation of speeds was calculated based on the 15 minute 85th percentile speeds. The data was further analyzed using various tables and graphs to determine trends and speed compliance. Each of these analyses is discussed in depth in the following section.

8.1 Speeds from Individual Vehicle Observations for Passenger Cars and Trucks

Individual vehicle speed observations were analyzed in Excel to determine the difference in speed behavior between cars and trucks. Figure 8-1 shows the 85th percentile speed behavior of cars and trucks using five minute averages for the December storm event. The data from Figure 8-1 is difficult to interpret due to the typical variations found in speed data; therefore the speeds were averaged over 15 minutes. Figure 8-2 shows the 15 minute average 85th percentile speed observations of cars and trucks for the December storm event. The other storm events show similar results to those shown in Figure 8-1 and in Figure 8-2. Refer to Appendix E for the complete set of speed observation figures for the other storm events.

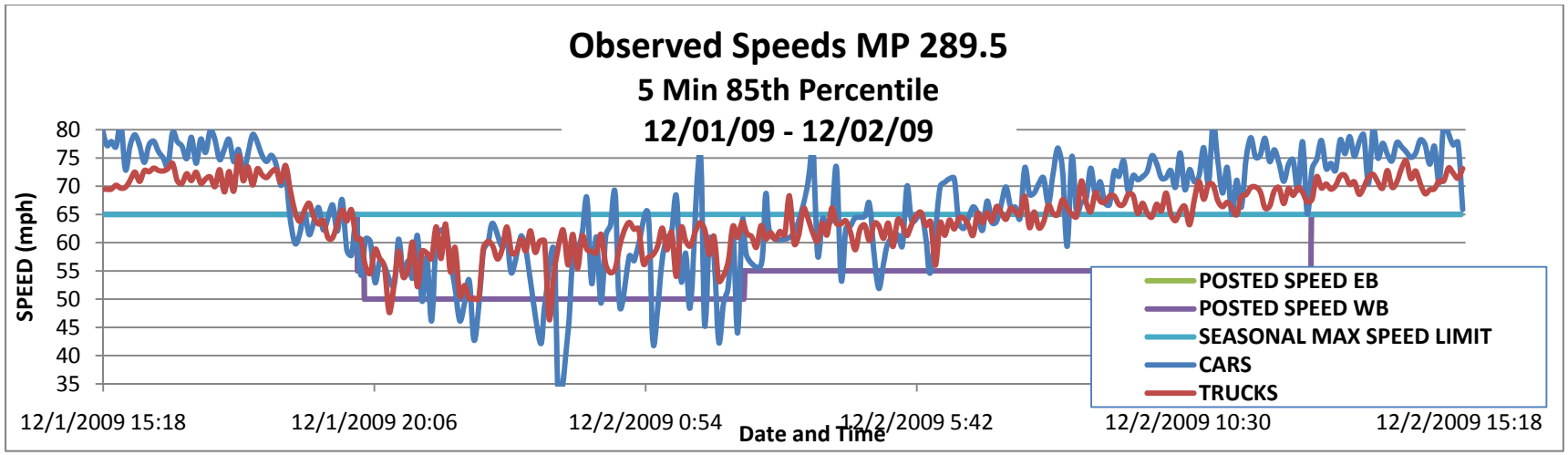

Figure 8-1: Observed speeds 5 minute average 85th percentile

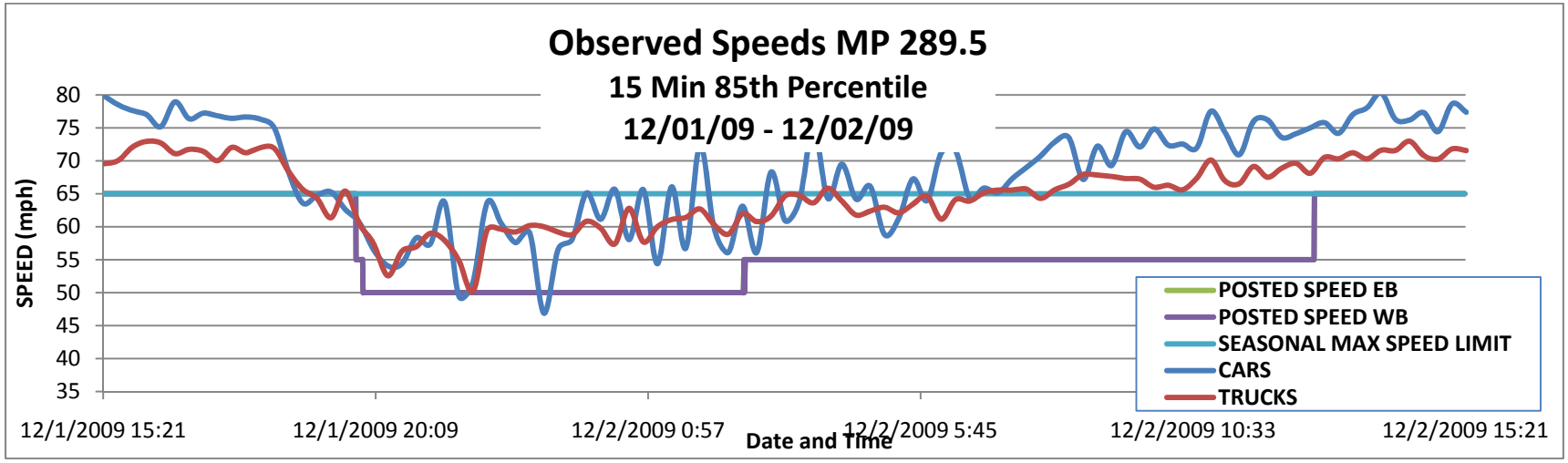

Figure 8-2: Observed speeds 15 minute average 85th percentile

From these graphs a general trend was observed that car speeds seemed to be higher than truck speeds. The individual vehicle data was further analyzed to statistically prove this observation. Excel was used to find the mean, standard deviation, variance, and number of observations for each milepost and storm event for both cars and trucks. The data from the cars and trucks were compared using the standard deviation of the difference in the means. The statistical test was run at a 95% confidence level for all cases. Table 8-1 shows the results from these tests. From Table 8-1 it can be seen that in general cars are traveling faster than trucks on I-80.

Table 8-1: Statistical significance in speed difference between cars and trucks

Event/Milepost	Statistically significant difference at 95% confidence?	Higher Speed
December 1-2,2009/ 256.25	Yes	Cars
December 1-2,2009/ 273.15	Yes	Cars
December 1-2,2009/ 289.50	Yes	Cars
February 3-4, 2010/ 256.25	Yes	Cars
February 3-4, 2010/ 273.15	Yes	Cars
February 3-4, 2010/ 289.50	Yes	Cars
March 18-21, 2010/ 256.25	Yes	Cars
March 18-21, 2010/ 273.15	Yes	Cars
March 18-21, 2010/ 289.50	Yes	Cars

8.2 Standard Deviation of Speeds from Individual Vehicle Observations for Passenger Cars and Trucks

The standard deviation of speeds was also calculated to determine if there was a significant difference in the standard deviation of speeds for cars as opposed to trucks. Reduction in standard deviation is believed to be related to improved safety of the roadway and is a goal of the VSL system. The standard deviation was calculated for 15 minute intervals of the individual observed speed data for cars and trucks for each milepost and storm event. Figure 8-3 shows the standard deviation for the March storm event at milepost 289.5 and is a representative example of the standard deviation graphs created. During the March storm event the road was closed for a period, which is why the graph shows the standard deviation as zero for a length of time. Refer to Appendix E for the complete set of standard deviation of speed figures. In general during ideal time periods the standard deviations of both cars and trucks is in the range of 4-6 mph. Also, during weather incidents the standard deviations of cars can be quite high (>10 mph). There was no consistent trend between standard deviations before and after the VSL system was implemented. The standard deviation data from the cars and trucks were compared using the standard deviation of the difference in the mean of the standard deviations. The statistical test was run at a 95% confidence level for all cases.

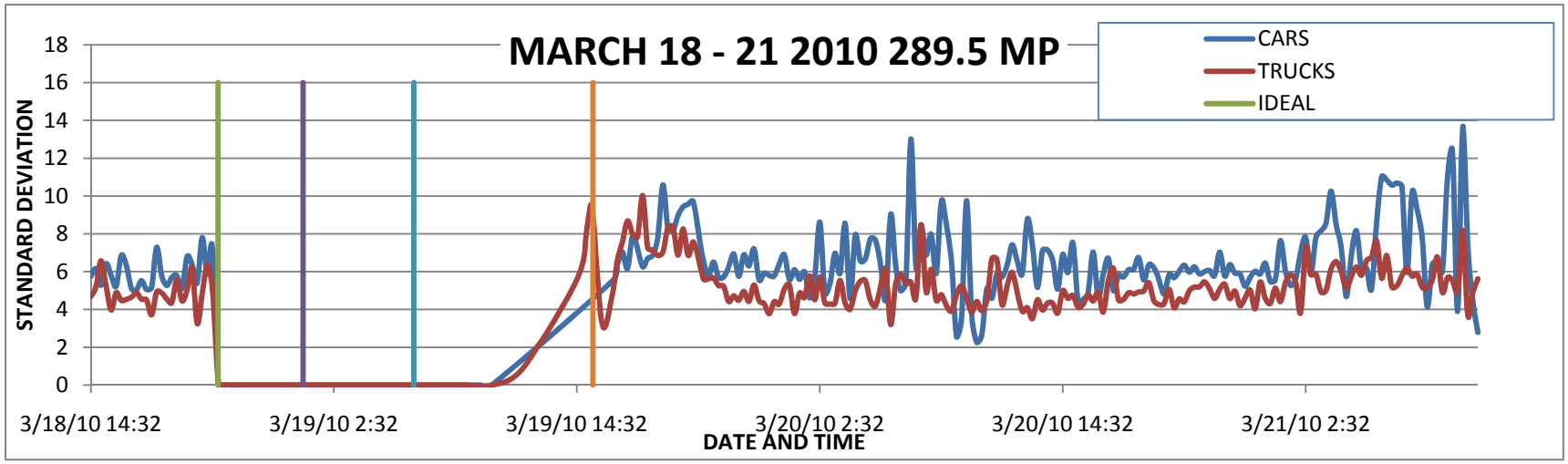

Figure 8-3: Standard deviation for 15 minute average 85th percentile speeds (*Note: Road closed from 3/18/10 20:40 to 3/19/10 10:20

Table 8-2 shows results from the statistical tests.

Table 8-2: Statistical significance in standard deviation difference between cars and trucks

Event/Milepost	Statistically significant difference?	Higher Standard Deviation
December 1-2,2009/ 256.25	No	N/A
December 1-2,2009/ 273.15	No	N/A
December 1-2,2009/ 289.50	No	N/A
February 3-4, 2010/ 256.25	Yes	Cars
February 3-4, 2010/ 273.15	Yes	Cars
February 3-4, 2010/ 289.50	Yes	Cars
March 18-21, 2010/ 256.25	Yes	Cars
March 18-21, 2010/ 273.15	Yes	Cars
March 18-21, 2010/ 289.50	Yes	Cars

For the December storm event there was no significant difference in the standard deviations of cars and trucks as seen in Table 8-2. For the storm events in February and March there was a significant difference in the standard deviations of cars and trucks with the cars having higher standard deviations.

8.3 Further Analyses of Standard Deviation and Speeds from Individual Vehicle Observations

For the Storm events the standard deviations and the speeds were further analyzed by categorizing the observations into four periods:

1. Observations under **ideal** conditions based on RWIS data to represent conditions before the storm event began,
2. Observations in the **transitional** period where RWIS data indicates worsening conditions but the variable speed limit not yet deployed,
3. Observations in the **initial** period of the VSL deployment, and
4. Observations in the **extended** period of VSL deployment where speeds are starting to increase but the VSL speeds remain constant.

Further analysis was only done on the storm events occurring in December and March as the VSL system was not implemented for the February storm event. For each of these time periods the average speed, 85th percentile speed, and standard deviations are calculated and summarized in a table for the three mileposts.

We would expect the standard deviations to be relatively low during the ideal periods and increase as the conditions worsen. After implementation of the VSL system ideally the standard deviations would be lowered.

Table 8-3, Figure 8-4, and Figure 8-5 are a representative example of the calculations and graphs created to further analyze the data. Refer to Appendix E for the complete set of tables and figures for all storm events.

Table 8-3: Further analyses of speed and standard deviation for December storm event

MILEPOST 289.5				
CARS	**IDEAL**	**TRANSITION**	**VSL IMPLEMENTED**	**EXTENDED VSL**
DURATION	12/1/2009 3:16:03 PM TO 12/1/2009 6:30:56 PM	12/1/2009 6:31:03 PM TO 12/1/2009 7:48:26 PM	12/1/2009 7:49:15 PM TO 12/2/2009 4:57:05 AM	12/2/2009 4:58:05 AM TO 12/2/2009 12:41:51 PM
# OBSERVATIONS	522	87	258	776
AVG SPEED	71.75	59.67	53.15	64.72
85th % SPEED	77.49	65.81	62.15	72.95
STD DEVIATION	5.68	7.22	8.93	7.40
TRUCKS	**IDEAL**	**TRANSITION**	**VSL IMPLEMENTED**	**EXTENDED VSL**
DURATION	12/1/2009 3:16:03 PM TO 12/1/2009 6:30:56 PM	12/1/2009 6:31:03 PM TO 12/1/2009 7:48:26 PM	12/1/2009 7:49:15 PM TO 12/2/2009 4:57:05 AM	12/2/2009 4:58:05 AM TO 12/2/2009 12:41:51 PM
# OBSERVATIONS	1136	378	1590	2447
AVG SPEED	67.03	57.46	53.12	61.66
85th % SPEED	71.50	65.10	60.70	67.10
STD DEVIATION	4.53	7.97	7.29	5.70
Calculations based on 15 minute Average Speeds				

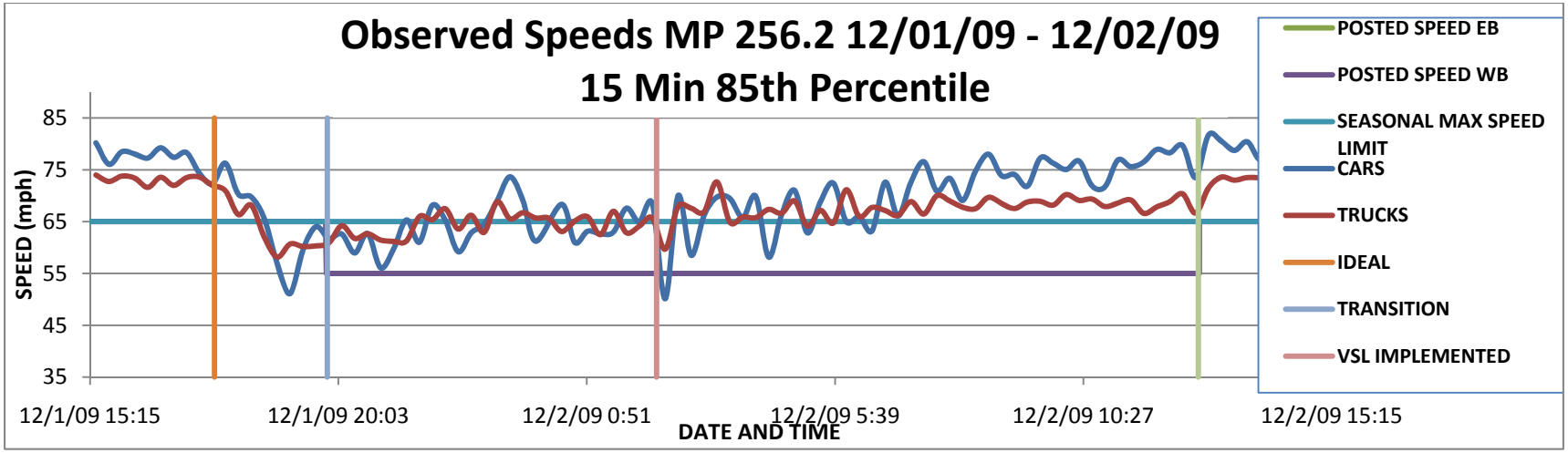

Figure 8-4: Observed speeds with VSL implemented

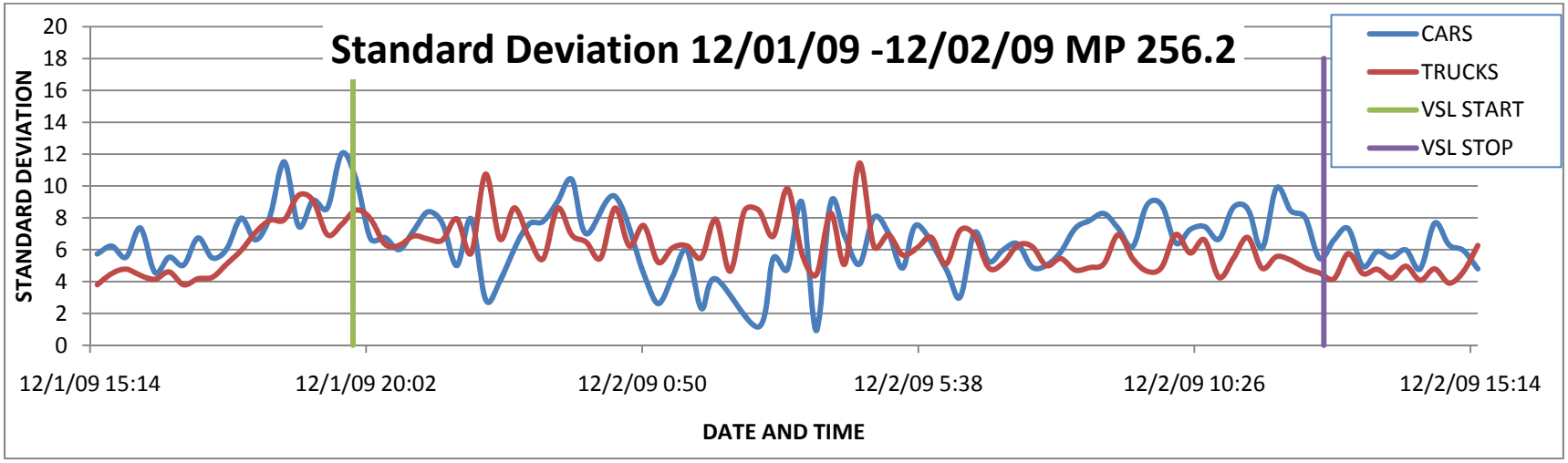

Figure 8-5: Standard deviation with VSL implemented

For Milepost 256.3 the standard deviations follow the expected pattern in that they are lowest during ideal conditions and highest during the transitional period. Implementation of the VSL appears to reduce the speed variation. For Mileposts 273.1 and 289.5 we do not see the same trend as the standard deviation instead increases after implementation of the VSL.

8.4 Speed Compliance from Individual Vehicle Observations

Speed compliance was defined for this analysis in two ways. The first was a *strict* definition that determined the percentage of vehicles that were observed going at or below the posted speed limit. The second was a more *lenient* definition where vehicles were considered compliant if they were going not more than 5 mph above the speed limit. The speed compliance value was calculated for the same four periods as the previous analysis (ideal, transitional, initial speed reduction, and extended speed reduction) for all three speed sensor locations. The percent of vehicles traveling well over the posted speed (>10 mph) was also determined. Table 8-4 and Figure 8-6 are examples of the speed compliance results. The results from the March 18-21, 2009 storm event show similar results. Speed compliance was not evaluated for the February 3-4, 2009 storm event. Refer to Appendix E for the complete set of tables and figures for all storm events.

Table 8-4: Speed compliance rates during December 1-2, 2009 storm event

	MILEPOST 256.2			MILEPOST 273.1			MILEPOST 289.5		
	% AT OR BELOW POSTED SPEED	% AT OR BELOW POSTED SPEED +5MPH	% AT OR ABOVE POSTED SPEED +10MPH	% AT OR BELOW POSTED SPEED	% AT OR BELOW POSTED SPEED +5MPH	% AT OR ABOVE POSTED SPEED +10MPH	% AT OR BELOW POSTED SPEED	% AT OR BELOW POSTED SPEED +5MPH	% AT OR ABOVE POSTED SPEED +10MPH
IDEAL PERIOD									
All Vehicles	13.5%	57.1%	14.0%	25.4%	62.4%	12.8%	27.2%	66.2%	12.7%
Cars Only	8.9%	35.9%	28.6%	14.1%	50.5%	23.4%	12.5%	41.2%	29.1%
Trucks Only	15.4%	65.4%	8.2%	31.2%	69.6%	8.5%	34.0%	77.6%	5.2%
TRANSITION PERIOD									
All Vehicles	80.8%	93.5%	1.2%	68.4%	91.3%	1.0%	83.7%	96.1%	1.1%
Cars Only	77.1%	88.0%	4.2%	66.0%	84.0%	4.0%	83.3%	97.6%	1.2%
Trucks Only	81.7%	94.7%	0.4%	71.5%	96.7%	0.0%	84.4%	96.6%	1.1%
INITIAL REDUCED SPEED									
All Vehicles	60.8%	79.0%	5.8%	55.4%	78.8%	6.1%	36.7%	64.1%	13.3%
Cars Only	61.8%	80.6%	5.8%	60.7%	80.3%	7.4%	38.8%	64.7%	18.6%
Trucks Only	57.8%	60.5%	9.0%	54.4%	78.3%	5.9%	36.4%	64.0%	12.5%
EXTENDED REDUCED SPEED									
All Vehicles	32.2%	53.9%	21.8%	11.3%	41.8%	22.9%	9.6%	34.2%	30.1%
Cars Only	28.9%	48.9%	31.5%	11.2%	42.4%	27.6%	7.3%	27.8%	43.2%
Trucks Only	39.2%	60.5%	17.5%	11.3%	41.7%	21.3%	10.3%	36.3%	26.0%

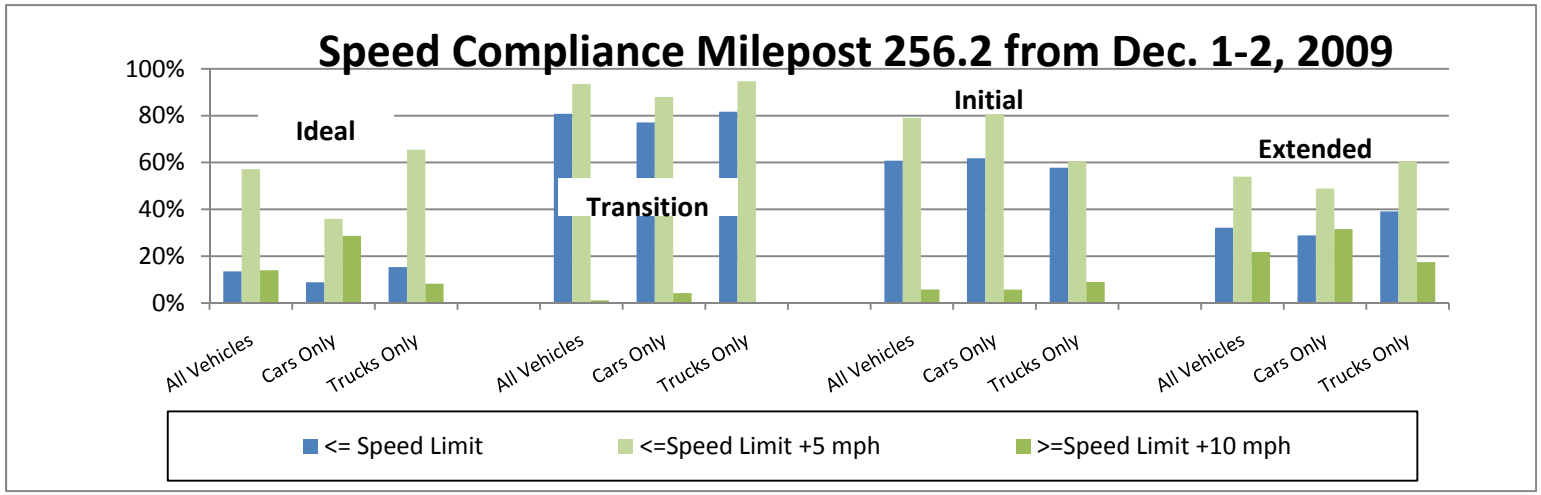

Figure 8-6: Speed compliance during December 1-2, 2009 storm event

Strict speed compliance was relatively low for the ideal period before the storm and ranged from 13% to 27% for all vehicles. At all locations, trucks had a higher compliance rate than cars. Using the more lenient definition of compliance the rates for the ideal period increased to 57% to 66% with trucks still having a higher rate of compliance. For the transition period the compliance rates were greatly increased to 68% to 96% likely indicating that it was difficult for most vehicles to travel the posted speed due to deteriorating road conditions. The lower compliance rates at milepost 273 may indicate that that section of road was not as affected by the storm as the other sections. For the initial speed reduction period the compliance rates were higher than those during the ideal period but lower than the transition period. The compliance rates for milepost 256 and 289 looked reasonable but the lower rates for milepost 289 may indicate that the speed was posted too low for conditions on that section. The extended speed reduction period had much lower compliance rates than the initial speed reduction period and this likely indicates that the conditions were improving but the speed limits were not increased. In particular the compliance rates for milepost 289 for this period are very low, even when the more lenient definition for compliance is used.

For the March 18-21, 2009 storm event strict speed compliance was relatively low for the ideal period before the storm and ranged from 13% to 22% for all vehicles. At all locations, trucks had a higher compliance rate than cars. Using the more lenient definition of compliance the rates for the ideal period increased to 50% to 56% with trucks still having a higher rate of compliance. For the transition period the compliance rates were greatly increased to 51% to 90% likely indicating that it was difficult for most vehicles to travel the posted speed due to deteriorating road conditions. The lower compliance rates

at milepost 273 may indicate that that section of road was not as affected as the other sections. As the corridor was closed from **March 18, 2010 8:50PM to March 19, 2010 10:20AM** we see no vehicles during that period of time. The extended speed reduction period had much lower compliance rates than the initial speed reduction period and this likely indicates that the conditions were improving but the speed limits were not increased. In particular the compliance rates for milepost 289 for this period are very low, even when the more lenient definition for compliance is used.

8.5 Speed Profiles

Using the individual data from each storm at each milepost, speed profiles were created to show vehicle speed versus the frequency of occurrence. The eastbound and westbound traffic was grouped together at each milepost to create the speed profiles. A speed profile was created for each of the four conditions that occurred during the storm event (ideal, transition, VSL implemented, and extended VSL) and for cars, trucks, and all vehicles. The speed profiles for cars, trucks, and all vehicles have been merged together to show the relationship between cars and trucks more clearly.

The speed profiles created for the December 1-2, 2009 storm event for milepost 256.25 for the merged speed profiles are shown in Figure 8-7, Figure 8-8, Figure 8-9, and Figure 8-10. When reviewing the speed profiles note the speeds on the x-axis as they shift slightly for each graph. Speeds are high during ideal conditions and then they begin to drop during the transition period. During the transition period the speeds are widely distributed showing large speed variation. When the VSL is implemented in Figure 8-9 and Figure 8-10 the speeds begin to have less variation and then start to increase again. Refer to Appendix E for the complete set of speed profiles for all the storm events.

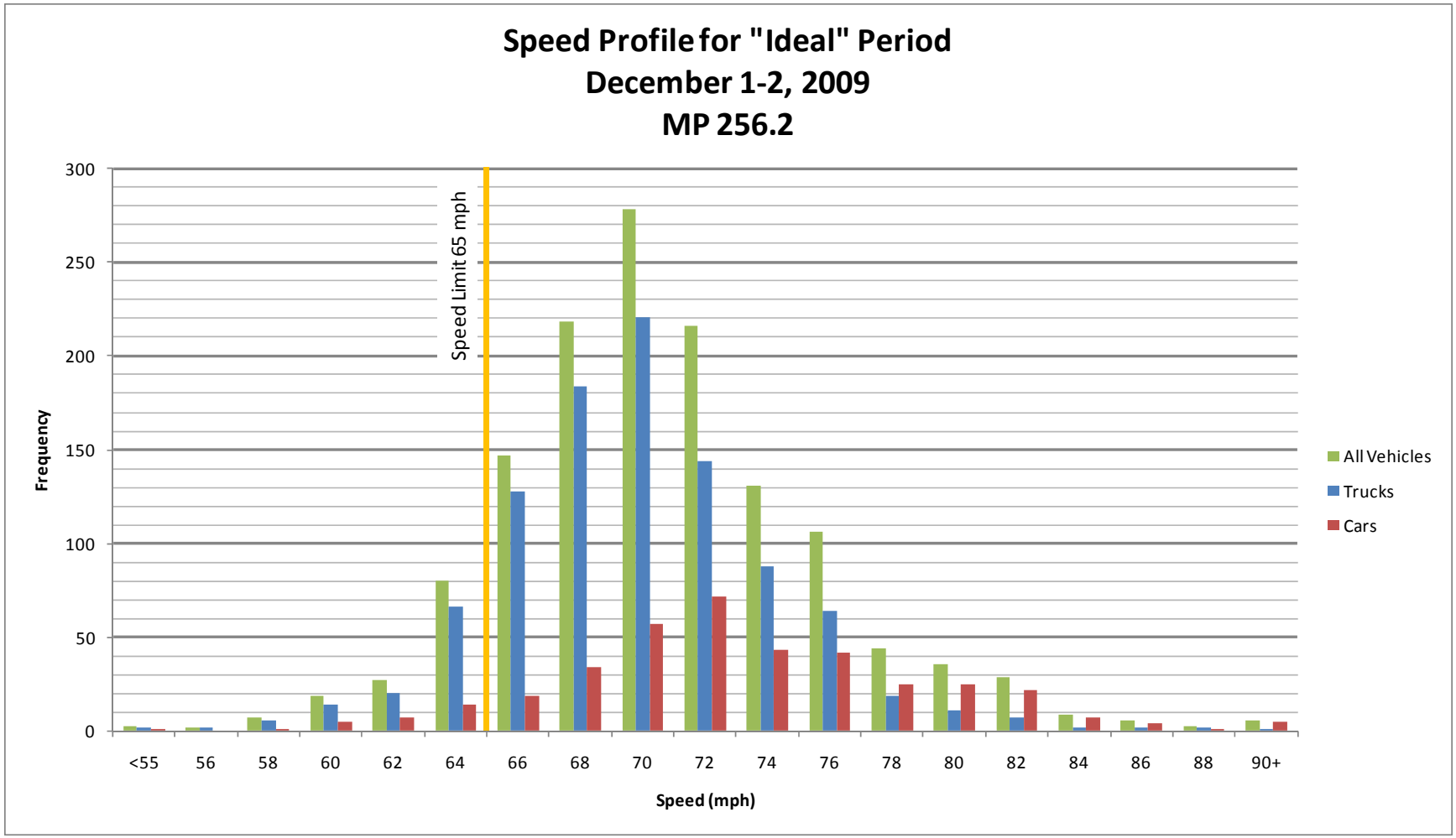

Figure 8-7: Ideal speed profile MP 256.25 December 1-2, 2009

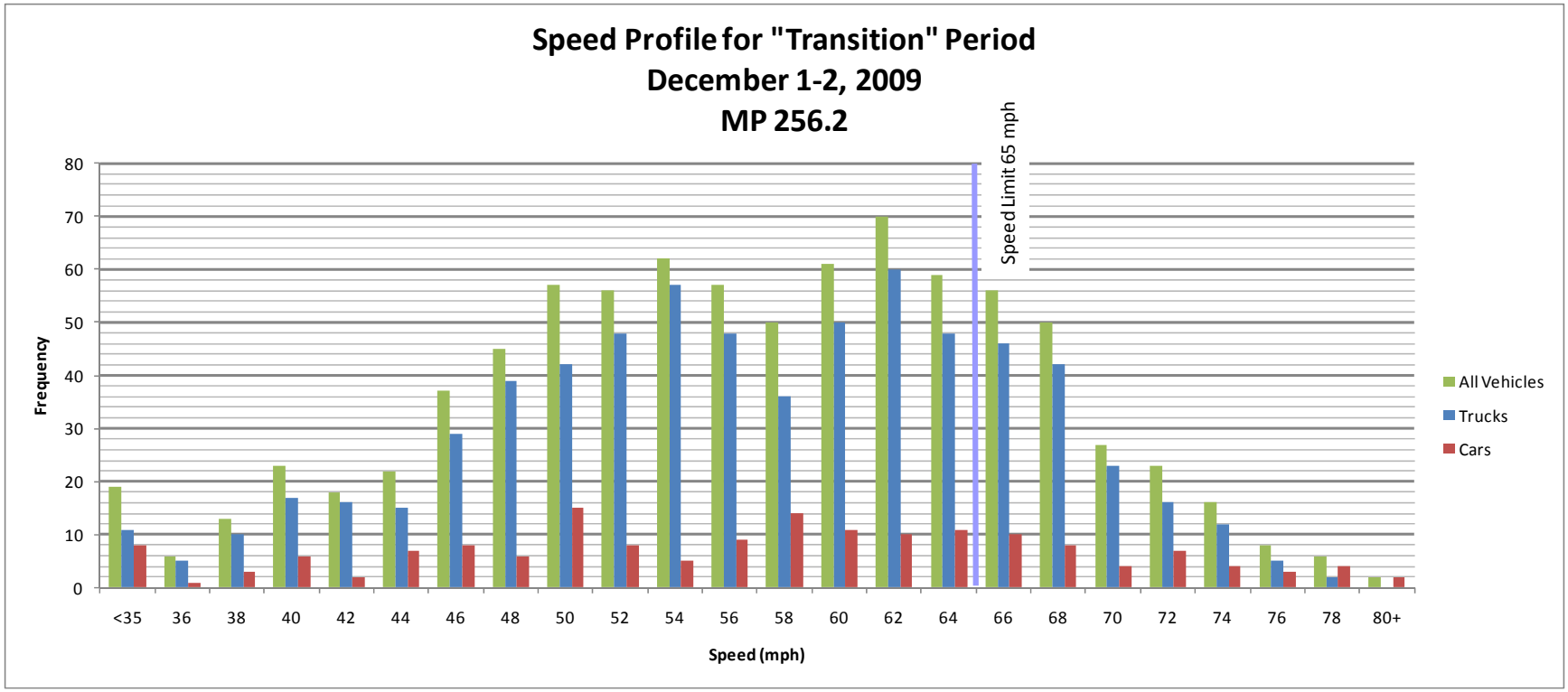

Figure 8-8: Transition speed profile MP 256.25 December 1-2, 2009

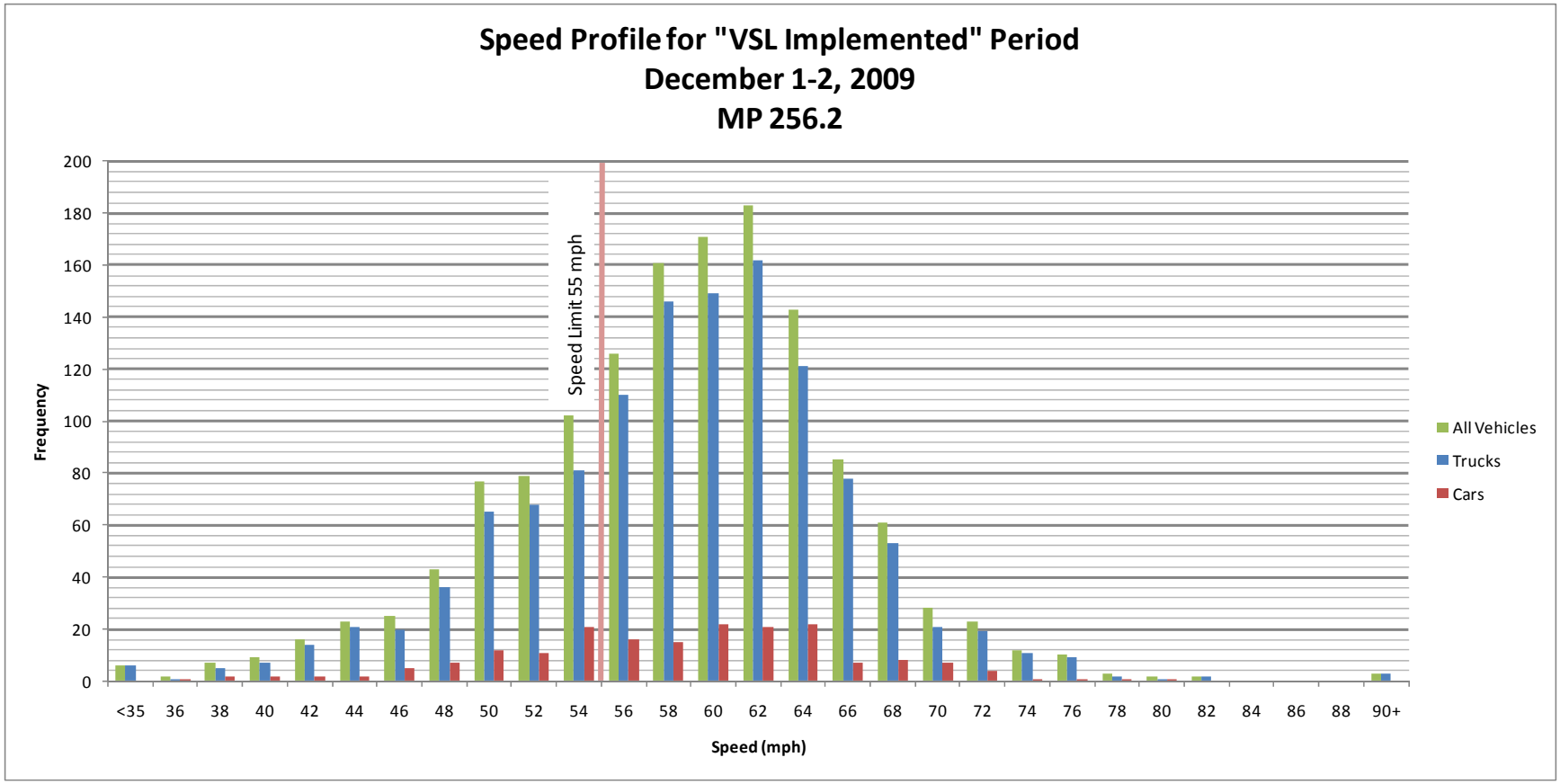

Figure 8-9: VSL implemented speed profile MP 256.25 December 1-2, 2009

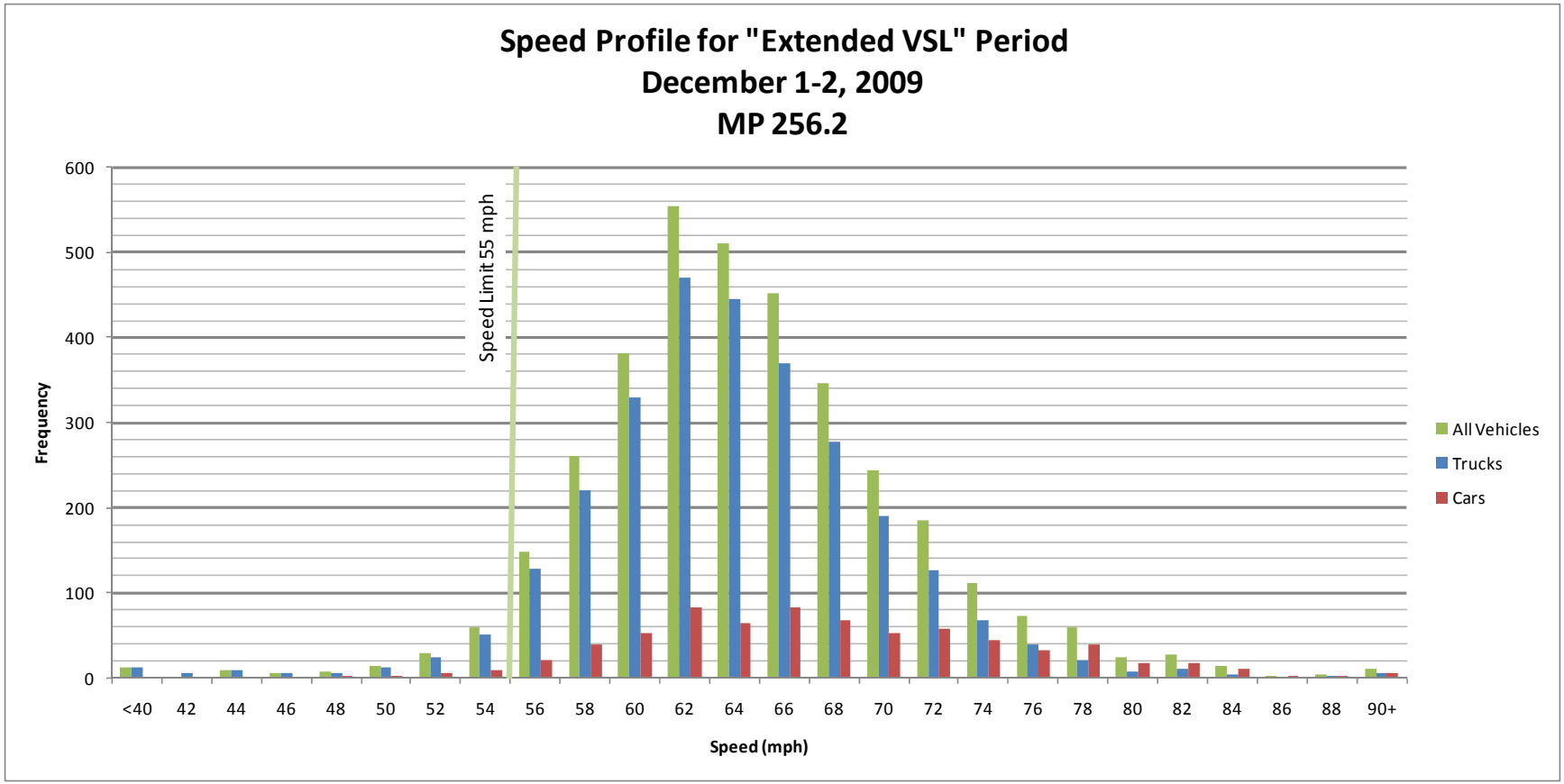

Figure 8-10: Extended VSL speed profile MP 256.25 December 1-2, 2009

8.6 Ideal Data Comparison

Ideal conditions are based on RWIS data and occur prior to storm events. Under ideal conditions the VSL system is not in use, meaning speeds are at the maximum speed limit for the particular time of year. Also, ideal conditions are only considered during daylight hours as drivers are affected differently during the nighttime. Data from two occurrences of ideal conditions was compared. The time periods for the ideal conditions were March 18, 2010 from 2:30 pm to 5:30 pm and June 5, 2010 from 2:30 pm to 5:30 pm. During the first time period the speed limit was at a seasonal maximum of 65 mph because it was during the winter. The speed limit during the second time period, which was in the summer, was 75 mph. The ideal data analyses were only done for a 3 hour time period due to the limited amount of ideal data for a time period with a 65 mph maximum speed limit. The following sections will explain the methods of data analyses and display the results of the comparison.

Speed Profiles

For each storm event speed profiles were created for each milepost for both the eastbound and westbound directions. Each speed profile contains data from cars, trucks, and all vehicles. Individual data was used to visually display the speed versus the frequency of its occurrence. Figure 8-11, Figure 8-12, and Figure 8-13 are representative examples of the speed profiles created for westbound traffic speeds on March 18, 2010 for all vehicles, cars only, and trucks only.

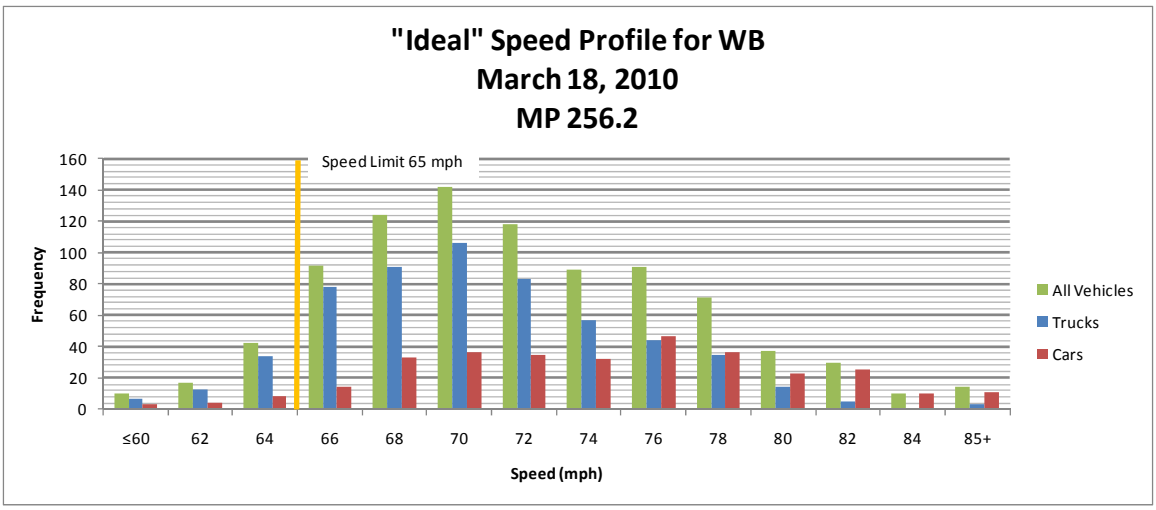

Figure 8-11: Milepost 256.2 Speed versus Frequency (Winter)

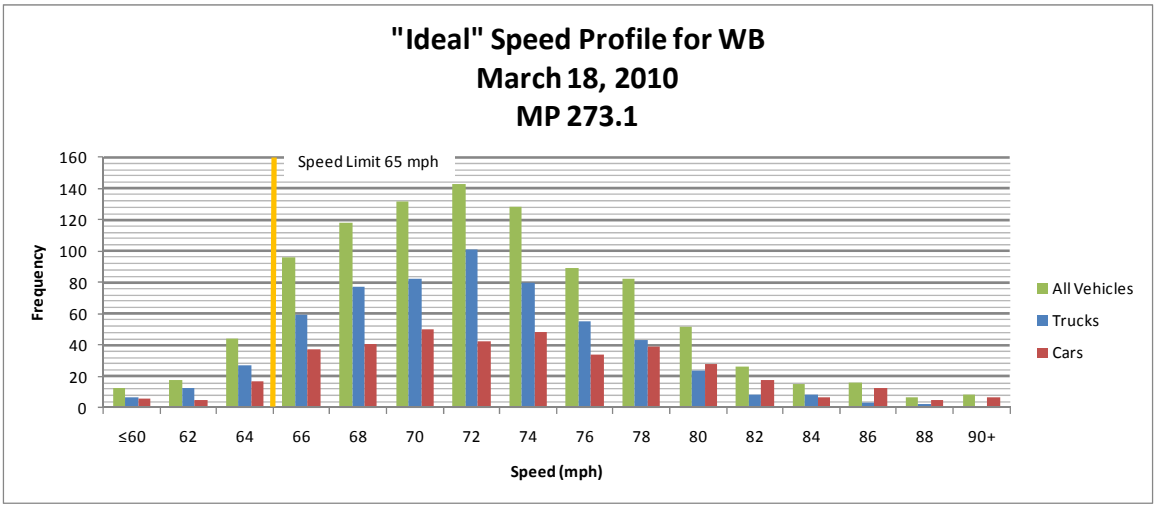

Figure 8-12: Milepost 273.1 Speed versus Frequency (Winter)

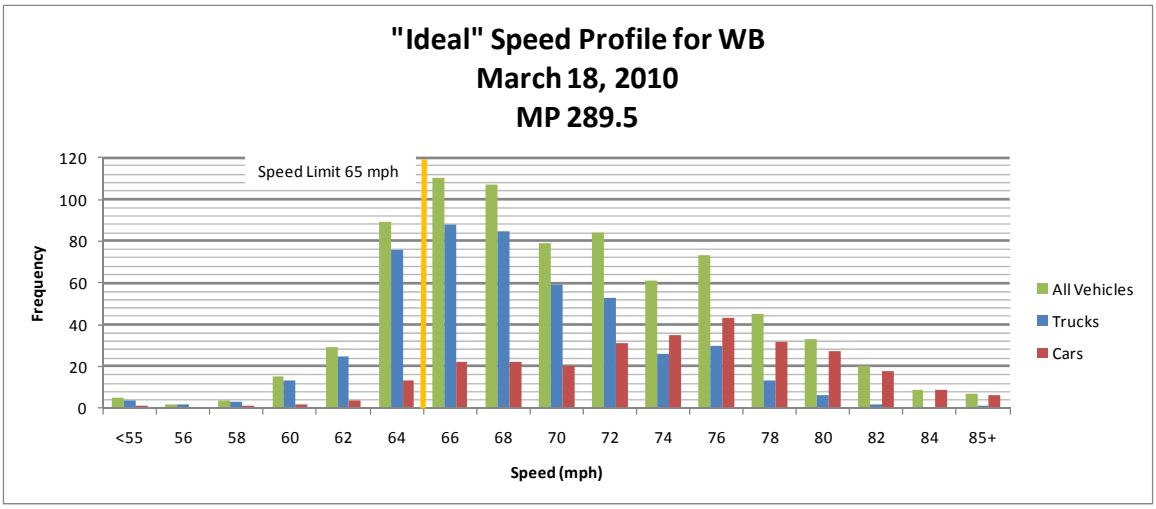

Figure 8-13: Milepost 289.5 Speed versus Frequency (Winter)

For the winter time period it was observed that during ideal conditions cars are driving faster than trucks. It must also be noted that all vehicles are tending to drive faster than the posted speed limit of 65 mph. Figure 8-11, Figure 8-12, and Figure 8-13 show speeds centered around 70 mph for all vehicles, 75 mph for cars, and 70 mph for trucks.

Figure 8-14, Figure 8-15, and Figure 8-16 are representative examples of the speed profiles created for westbound traffic speeds on June 5, 2010 for all vehicles, cars only, and trucks only. The speed limit was 75 mph for this time period.

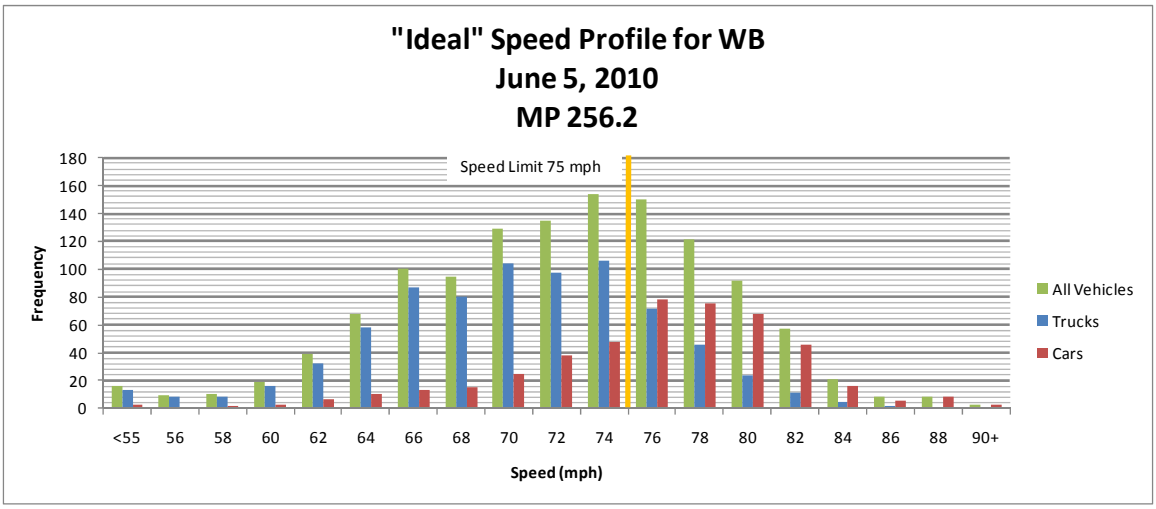

Figure 8-14: Milepost 256.2 Speed versus Frequency (Summer)

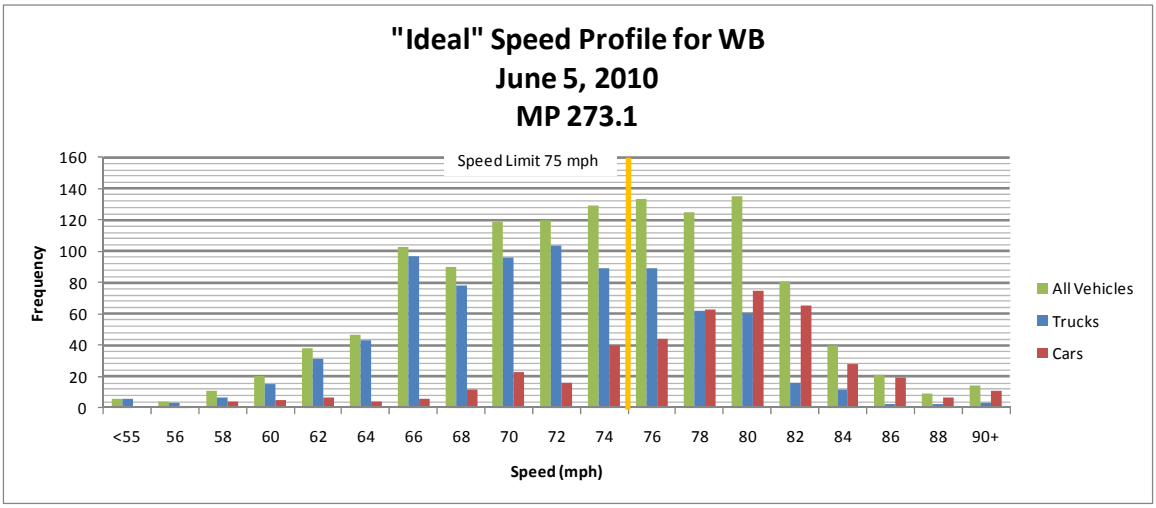

Figure 8-15: Milepost 273.1 Speed versus Frequency (Summer)

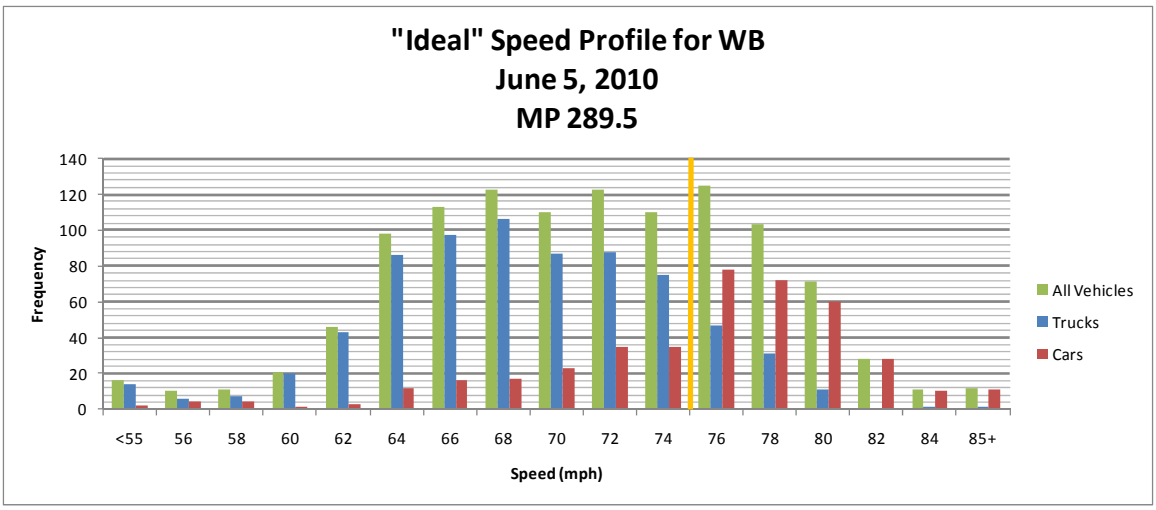

Figure 8-16: Milepost 289.5 Speed versus Frequency (Summer)

From Figure 8-14, Figure 8-15, and Figure 8-16 it was observed that cars are generally travelling faster than trucks during ideal conditions. The speed profile for cars is centered around 77 mph while for trucks it is centered around 73 mph. The speed profile of all vehicles is centered on 75 mph. Refer to Appendix E for the set of speed profiles for the eastbound direction. The westbound speed profiles shown in this chapter showed similar characteristics to the eastbound speed profiles.

Statistical Analyses

The data analysis tool in Excel was used to calculate various statistics for each group of data. Statistics were calculated for each time period, at each milepost, in both the eastbound and westbound directions. Table 8-5 and Table 8-6 show the calculated statistics for the winter and summer periods respectively for milepost 256.2 in the westbound direction.

Table 8-5: Statistics for All Vehicles (Winter)

WB 256.2 March 18, 2010	
85th Percentile	76.7
Mean	70.95
Standard Error	0.19
Median	70.30
Mode	70.80

Standard Deviation	5.65
Sample Variance	31.97
Kurtosis	2.40
Skewness	0.57
Range	61.10
Minimum	46.30
Maximum	107.40
Sum	62932.00
Count	887.00
Confidence Level(95.0%)	0.37

Table 8-6: Statistics for All Vehicles (Summer)

WB 256.2 June 5, 2010	
85th Percentile	78.1
Mean	71.42
Standard Error	0.19
Median	72.00
Mode	73.80
Standard Deviation	6.64
Sample Variance	44.05
Kurtosis	0.73
Skewness	-0.44
Range	54.80
Minimum	39.50
Maximum	94.30
Sum	88132.80
Count	1234.00
Confidence Level(95.0%)	0.37

Table 8-5 shows statistics from the time period when 65 mph was the maximum speed limit yet the 85th percentile speed is 76.7 mph. This demonstrates that vehicles will drive the speed they determine to be appropriate for the conditions regardless of what the posted speed limit actually is. It is also important to note that the standard deviation for this specific data set is relatively low at only 5.65 mph. Table 8-6 shows statistics from the time period when 75 mph was the maximum speed limit and the 85th percentile speed is 78.1 mph. The standard deviation for this data set is also relatively low at only 6.64 mph. Refer to Appendix E for the complete set of statistical analyses tables for every milepost, direction, and time period.

Speed Compliance

Speed compliance was defined for this analysis in two ways. The first was a *strict* definition that determined the percentage of vehicles that were observed going at or below the posted speed limit. The second was a more *lenient* definition where vehicles were considered compliant if they were going not more than 5 mph above the speed limit. The percent of vehicles traveling well over the posted speed (>10 mph) was also determined. Table 8-7 and Table 8-8 show the speed compliance results from each milepost for both the summer and winter time periods of ideal data.

Table 8-7: Speed Compliance (Winter)

IDEAL PERIOD	MILEPOST 256.2			MILEPOST 273.1			MILEPOST 289.5		
	% AT OR BELOW POSTED SPEED	% AT OR BELOW POSTED SPEED +5MPH	% AT OR ABOVE POSTED SPEED +10MPH	% AT OR BELOW POSTED SPEED	% AT OR BELOW POSTED SPEED +5MPH	% AT OR ABOVE POSTED SPEED +10MPH	% AT OR BELOW POSTED SPEED	% AT OR BELOW POSTED SPEED +5MPH	% AT OR ABOVE POSTED SPEED +10MPH
All Vehicles	13.03%	49.65%	19.32%	20.14%	54.46%	19.00%	22.45%	55.96%	17.77%
Cars Only	5.21%	31.64%	32.63%	11.16%	46.88%	26.71%	8.87%	33.66%	33.05%
Trucks Only	18.44%	62.09%	10.12%	28.00%	61.09%	12.25%	33.02%	73.32%	5.87%

Table 8-8: Speed Compliance (Summer)

IDEAL PERIOD	MILEPOST 256.2			MILEPOST 273.1			MILEPOST 289.5		
	% AT OR BELOW POSTED SPEED	% AT OR BELOW POSTED SPEED +5MPH	% AT OR ABOVE POSTED SPEED +10MPH	% AT OR BELOW POSTED SPEED	% AT OR BELOW POSTED SPEED +5MPH	% AT OR ABOVE POSTED SPEED +10MPH	% AT OR BELOW POSTED SPEED	% AT OR BELOW POSTED SPEED +5MPH	% AT OR ABOVE POSTED SPEED +10MPH
All Vehicles	59.72%	87.13%	2.13%	62.29%	88.11%	2.49%	63.63%	89.87%	2.16%
Cars Only	32.52%	74.75%	4.85%	35.55%	74.83%	5.19%	32.71%	77.95%	4.70%
Trucks Only	79.41%	96.09%	0.16%	77.62%	95.91%	0.97%	86.15%	98.55%	0.30%

During the winter time period speed strict speed compliance is very low with a maximum of 22.45% for all vehicles occurring at milepost 289.5. During the summer time period compliance is much higher with a maximum of 63.63% for all vehicles occurring at milepost 289.5. Figure 8-17 and Figure 8-18 are representative examples of the speed compliance graphs made for the winter and summer periods respectively. From these figures it is easy to see the low rates of speed compliance in the winter when the speed limit was 65 mph as opposed to the much higher rates of speed compliance in the summer when the speed limit was 75 mph.

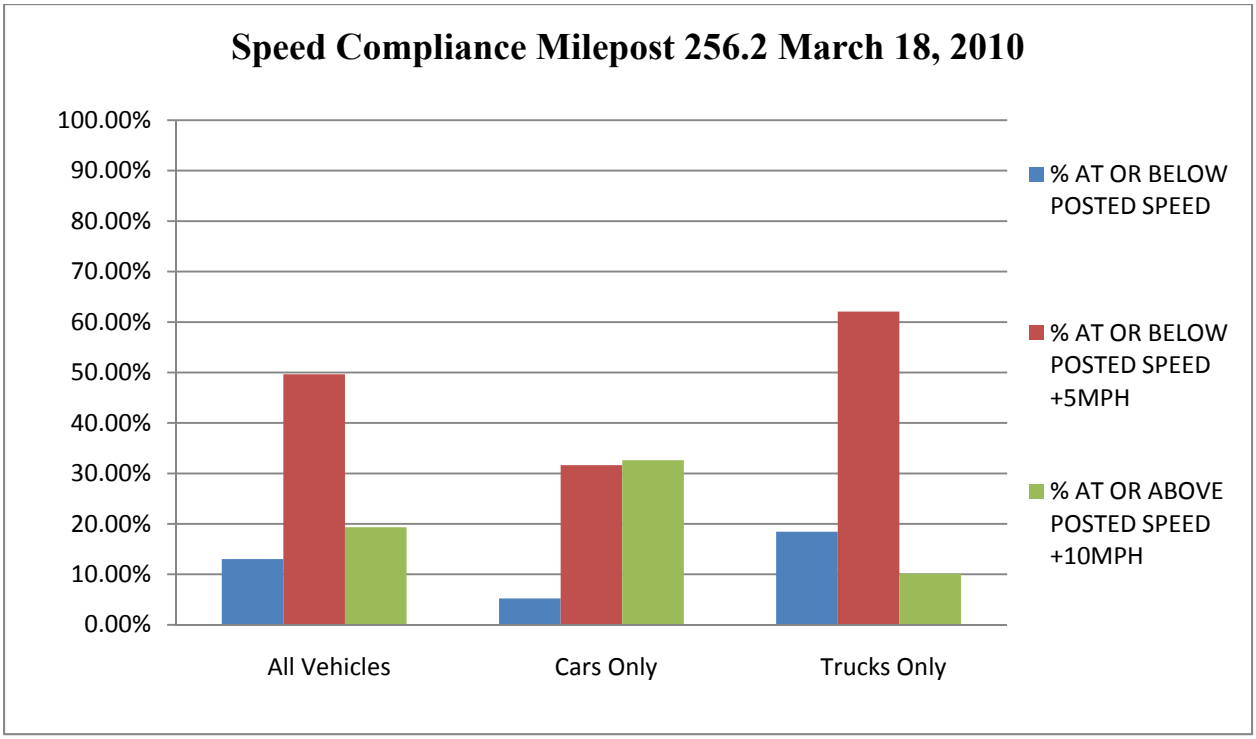

Figure 8-17: Winter Speed Compliance

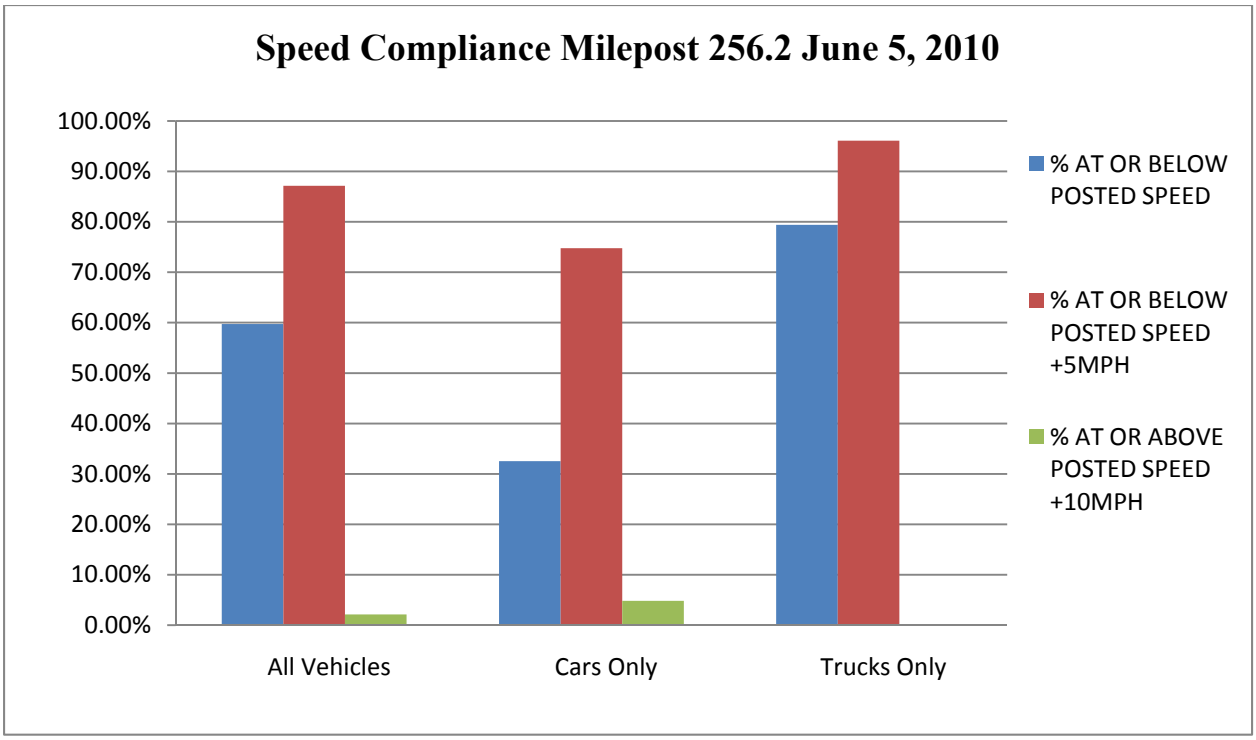

Figure 8-18: Summer Speed Compliance

Chapter 9 Draft VSL Control Strategy

Variable Speed Limits (VSL) are used to improve traffic safety and increase the speed compliance of drivers by displaying recommended or enforced speed limits posted by Traffic Management Centre (TMC) operators based on real-time conditions. Currently on the Elk Mountain VSL corridor uses a manual protocol that was described in Chapter 4. This interim protocol relies on highway patrol or maintenance personnel traveling the corridor to make the decision that the conditions warrant speed changes and then to notifying the TMC of the speed limit that should be posted. There were two main reasons for implementing this type of manual protocol at the initial stages of the VSL system. The first was that the VSL system was installed before there was time to analyze the weather and speed data from the corridor in order to develop a control strategy based on real time data. The second reason for a protocol that relied on observations of personnel in the field was that there was limited technology in the corridor to collect weather information and to visual verify conditions through roadside cameras. Over the last twelve months new RWIS stations and roadside cameras have been installed (described in Chapter 4) that provide the TMC with a more accurate picture of conditions along the entire corridor. This allows for the use of a VSL control strategy that would initiate the process to rise or lower posted speeds based on real-time weather and speed data instead of relying of personnel in the field to initiate the change. The intention is not to fully automate the process so verification of conditions and authorization of the recommended speed limits would still be done by TMC operators.

A control strategy is a set of conditions based on corridor weather and speed data that determines recommended speed limits that are reasonable for the current driving conditions. The recommended speed limits are set to be neither too high nor too low for the given weather

conditions. The use of a control strategy will provide better consistency for drivers. An automated control strategy that is part of a decision support system used in software at the TMC will also make the speed limit changes timelier with respect to changing conditions on the corridor. The increased consistency and responsiveness of the system should help with the speed compliance issues that were discussed in Chapter 8 and illustrated Figure 8-1.

This chapter explains the methodology used to develop a draft control strategy based on speed and weather data collected on the corridor from the analyses described in Chapter 7. The control strategy was tested using a simulation of an actual storm event on the corridor to verify that it would work as expected. The draft control strategy is meant as a starting point for discussions within WYDOT. The draft control strategy will be reviewed and modified over the next several months before being tested during the 2010-2011 winter season.

9.1 Development of Draft VSL Control Strategy

Individual speed data from three mileposts (256.25, 273.15 and 289.5) that was collected during a storm event on December 1-2, 2009 was merged with RWIS data and DMS data for the development of the Draft VSL Control Strategy. After performing quality checks, the three files are merged and then categorized into 9 different bins based on the observed speeds. To determine which RWIS variables should be used in the draft control strategy, graphs were made between speeds and the candidate RWIS variables to determine the relationship between the different variables. The threshold values for the RWIS variables were then selected and the overall draft control strategy was created. Each of these tasks will be described further in the following sections.

Categorizing the Data

The merged speed, weather, and posted speed dataset was categorized based on the observed individual vehicle speeds. The speed bins categorizations are shown in Table 9-1 below. Bin range categories were selected to ensure that there is no speed bias in the data since the range is balanced around the posted speeds.

Table 9-1: Speed Ranges for Speed Categories

Bin Range (MPH)	Speed Limit (MPH)
> = 73	75
67-73	70
63-67	65
57-63	60
53-57	55
47-53	50
43-47	45
37-43	40
< = 37	35

Selection of RWIS Variables

The results from the analyses described in Chapter 7 suggest several RWIS variables that were shown to have a statistically significant impact on observed speed. The RWIS variables which are served as a starting point for use in the draft control strategy are:

- Surface temperature,
- Sub temperature,
- Air temperature,
- RH,
- Dew point,
- Average wind speed,
- Gusty wind speed, and
- Visibility.

Each of these variables was plotted against speed to determine if patterns could be observed. Figure 9-1 and Figure 9-2 show the graphs of speed versus visibility and speed versus relative humidity. From Figure 9-1 it is clear that visibility was following a similar pattern as speed and that as visibility decreases so does speed. From Figure 9-2 an opposite relationship can be seen between speed and relative humidity (RH). The graphs for the remaining RWIS variables can be found in Appendix F. From this task the variables that showed a recognizable pattern with speed were visibility, surface temperature, air temperature. Average wind speed and wind gust speeds followed a recognizable pattern during the initial part of the storm but as the storm continues the pattern is less observable. The dew point variable did not follow a strong pattern with respect to speed. For the draft version of the control strategy visibility, surface temperature, RH, surface status and precipitation type RWIS variables were used. Other RWIS variables like dew point, average wind speed and wind gust speed were shown to be significant in the statistical analysis (see Chapter 7). Further analyses will be done during the second Phase of this research on those variables to determine if and how they should be incorporated into the Control Strategy.

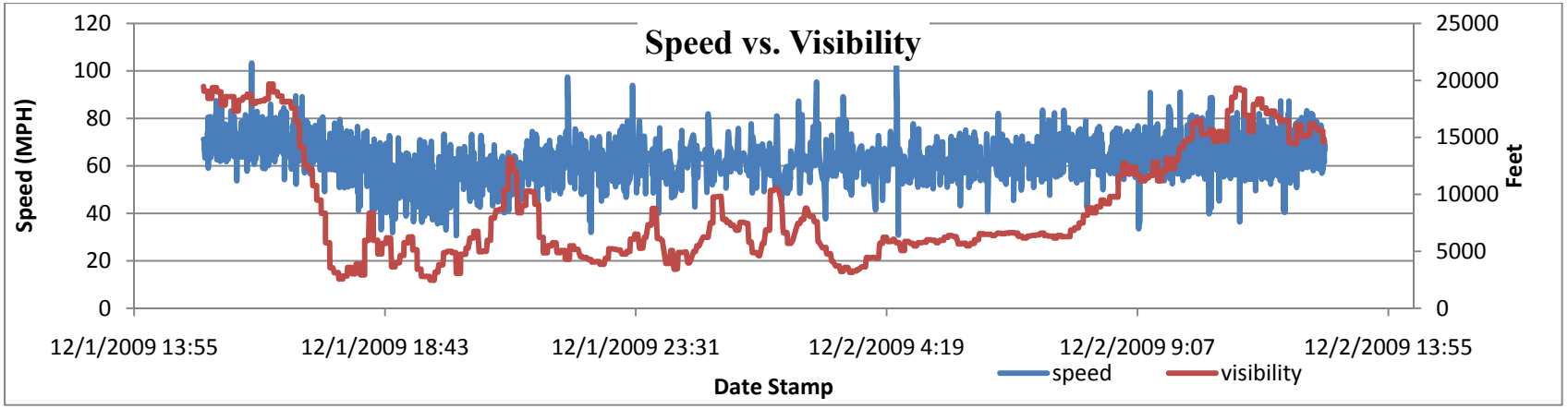

Figure 9-1: Speed vs. Visibility

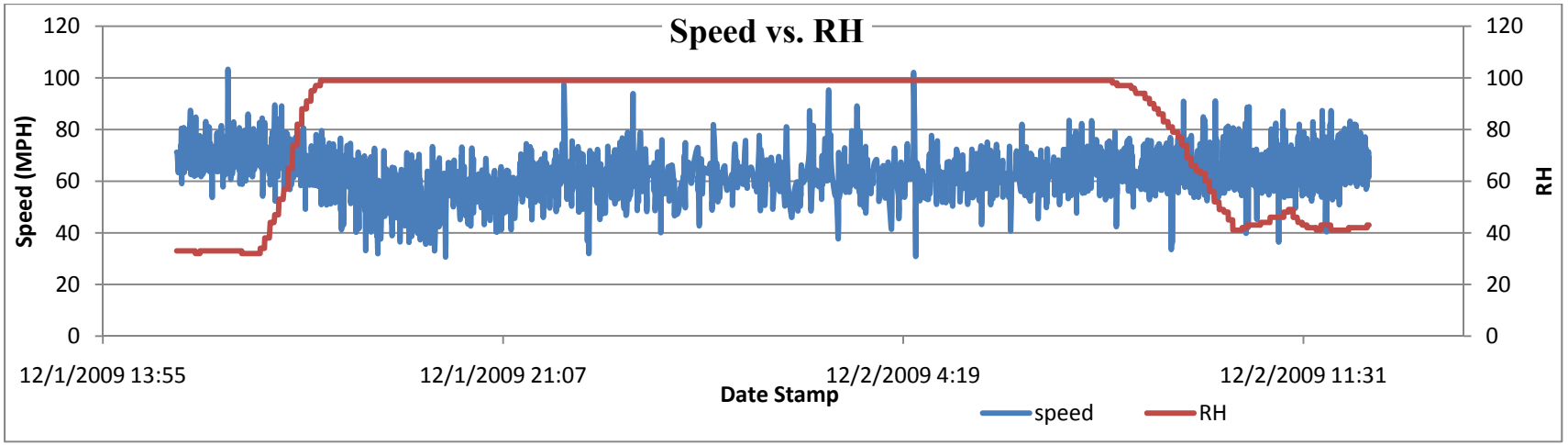

Figure 9-2: Speed vs. RH

Thresholds

To construct the control strategy logic based on the candidate RWIS variables, thresholds need to be selected that suggest the appropriate speed limit according to the varying weather conditions. To select the threshold values, the individual speed data and the storm data from October 15th to December 15th 2009 was collected and categorized into nine different files based on speed ranges which are shown in Table 9-2. Each speed range was analyzed to get the thresholds for the RWIS variables. The maximum, minimum, 85th percentile and average values were found for the variables surface temperature, air temperature, RH, dew point, average wind speed, wind gust speed and visibility in all categories. Table 9-3 shows the percentage of vehicles travelling during different pavement conditions and precipitation type.

Table 9-2: Visibility Variable Statistics

	VISIBILITY (Ft)			
MPH	**MAX**	**MIN**	**AVERAGE**	**85th PERCENTILE**
75	19,687	2,575	14,928	18,420
70	19,687	2,575	14,411	18,166
65	19,687	2,470	13,344	18,106
60	19,687	2,470	10,935	16,742
55	19,319	2,470	9,105	15,675
50	16,521	2,470	6,299	8,708
45	15,623	2,791	6,158	8,433
40	13,143	2,470	6,404	8,708
35	13,143	2,470	6,795	8,708

Table 9-3: Percentage of vehicles travelling during different pavement condition and precipitation type

Precipitation and Surface status	**Snow and Wet**	**None and Wet**	**None and Dry**
MPH	**%**	**%**	**%**
75	3	7	90
70	4	9	87
65	5	13	82
60	8	19	73

55	15	29	55
50	36	36	28
45	67	27	6
40	78	20	2
35	84	15	1

Selection of proper thresholds is crucial as the entire control logic is dependent on this, so considering average values in each category does not provide the clearest picture of driver behavior while 85th percentile values gives a better estimate and is a more commonly used indicator in the field of traffic engineering. In order to obtain most appropriate threshold values the maximum, minimum, average and 85th percentile values were found for the data which was sub categorized depending on surface status and surface type, which is shown in Table 9-5. After analyzing the data of all different categories tentative thresholds were obtained for the variables that were shown previously to be statistically significant and were verified by finding visible patterns. Visibility, Surface temperature, and RH are shown in the Table 9-4.

Table 9-4: Tentative thresholds for RWIS variables

MPH	Visibility	Surface Temp	RH
75	>15000	>28	<48
70	>13500	>27	50-99
65	>13000	>25	58-99
60	>12000	>20	72-99
55	>11000	>18	80-99
50	>8000-11000	<25	90-99
45	5500-8000	<25	98-99
40	3500-5500	<25	98-99
35	<3500	<20	99
ROADS CLOSED			

Table 9-5: Maximum, minimum, average and 85th percentiles after sub categorizing 55mph category according to surface type and precipitation type for MP 282.5 October to December storm event

TOTAL	COUNT	DRY AND NONE									
1074	137		MPH	SfTemp	SubTemp	AirTemp	RH	Dewpoint	AvgWindSpeed	GustWindSpeed	Visibility
	13%	MAX	56.99	64.40	54.00	56.00	95.00	29.00	43.00	57.00	19,900
		MIN	53.00	4.10	19.00	1.00	10.00	-14.00	0.00	2.00	253
		AVERAGE	55.55	27.95	33.72	29.55	36.92	4.70	28.47	38.18	11,519
		85TH PERCENTILE	56.65	46.62	46.00	49.00	56.80	18.60	40.00	52.00	15,633
	COUNT	WET AND NONE									
	465		MPH	SfTemp	SubTemp	AirTemp	RH	Dewpoint	AvgWindSpeed	GustWindSpeed	Visibility
	43%	MAX	56.99	41.50	49.00	37.00	99.00	33.00	48.00	60.00	20,375
		MIN	53.01	-7.40	19.00	-11.00	33.00	-13.00	0.00	0.00	253
		AVERAGE	55.30	13.65	28.98	9.54	87.46	6.04	13.11	18.45	43,91
		85TH PERCENTILE	56.63	24.56	35.00	21.00	99.00	16.00	23.00	31.00	8,285
	COUNT	WET AND SNOW									
	472		MPH	SfTemp	SubTemp	AirTemp	RH	Dewpoint	AvgWindSpeed	GustWindSpeed	Visibility
	44%	MAX	56.99	46.40	52.00	44.00	99.00	39.00	45.00	66.00	23,593
		MIN	53.00	-3.50	19.00	-6.00	58.00	-7.00	0.00	0.00	348
		AVERAGE	55.07	18.85	32.26	14.31	97.25	13.83	14.02	19.06	4,926
		85TH PERCENTILE	56.46	27.30	39.00	24.00	99.00	24.00	34.00	43.00	7,881

Development of the overall draft control strategy was split into two stages. The first focused on the control strategy from the observed speed perspective and the second focused on the candidate RWIS variables discussed in the previous section.

Observed Speed Perspective

The observed speed patterns typically provide a very clear picture about what is happening on the roadway during different conditions. In order to get the information required for the control logic the following methodology was used to determine a recommended posted speed based on real time observed speeds.

1. Speed sensor data subjected to quality checks to ensure the sensors are reporting reasonable data.
2. Calculate the 85th percentile speeds and vehicle counts were calculated for every fifteen minute period.
3. Low Volume Filter: Based on the 2009 AADT value of 11,090 for the corridor, it was decided that if the count of the vehicles during the fifteen minute bin is less than or equal to 40 the average of current and previous <u>two</u> fifteen minute 85th percentile speeds were considered as the new candidate speed limit to be posted. If the count falls between 40 and 60 then the average of current and <u>one</u> previous fifteen minute 85th percentile speeds were considered as a new candidate speed limit. This filter prevents speed observations during very low volumes from carrying too much weight within the control strategy.
4. Speed Rounding Filter: If the speeds calculated from the Low Volume filter fall within the bin range as shown in Table 9-1 they were rounded to the posted speed limit shown in right column of Table 9-1 so that only speeds in five mile increments and that are available on the scrolling film of the dual film VSL signs would be recommended..

5. After speed rounding filter was applied the new recommended posted speed limits were determined.

The methodology was applied to data sets collected for the research project to run a simulated test of the control strategy. A similar process could be followed using real-time inputs.

Weather Variable Perspective

The dependencies of the control logic on the RWIS variables are crucial, so it is important to have a reliable RWIS station. The candidate threshold values which are calculated and shown in Table 9-4 are used in the methodology for determining the recommended posted speed limits. The steps outlining the methodology are described below.

1. RWIS and speed data subjected to quality checks to ensure that the individual sensors are working properly. .
2. Threshold Filter: Nine sub filters were created using the calculated thresholds shown in Table 9-4.
    a. Sub Filter 1: Thresholds of 75 mph limit are applied along with the surface status and precipitation type conditions (surface conditions can be either dry or wet and precipitation type should be none).
    b. Sub Filter 2: Thresholds of 70 mph along with surface status of dry or wet and precipitation type none conditions.
    c. Sub Filter 3: Thresholds of 65 mph along with surface status of dry or wet and precipitation type none conditions.
    d. Sub Filter 4: Thresholds of 60 mph along with surface conditions of wet and precipitation type none or snow.

e. Sub Filter 5: Thresholds of 55 mph along with surface conditions of wet and precipitation type none or snow.

f. Sub Filter 6: Thresholds of 50 mph along with surface conditions of wet and precipitation type none or snow.

g. Sub Filter 7: Thresholds of 45 mph along with surface conditions of wet and precipitation type snow.

h. Sub Filter 8: Thresholds of 40 mph along with surface conditions of wet and precipitation type snow.

i. Sub Filter 9: Thresholds of 35 mph along with surface conditions of wet and precipitation type none or snow.

3. Filter 2: Any data that is missing from the previous through this sub filters will pass through the visibility threshold filter. This will ensures that there is no data missing.
4. Filter 3: Calculate the 85th percentile of the data that passed through the filter 2.
5. Speed Rounding Filter: The speeds which are obtained from filter 3 are converted to a recommended posted speeds based on the speed bin ranges shown in Table 9-1.
6. New recommended posted speed based on variables is found after applying the speed rounding filter.

After obtaining the speeds limits from both the speed and RWIS methodologies, the data should pass through a final filter which combines the two recommendations (if different) . The Final filter is:

- If the difference between speeds obtained from the RWIS perspective and speed perspective is greater than 15 mph then the RWIS limit should be used. Otherwise the speed perspective limits are used.

9.2 Simulation

The draft control logic described in the previous section was applied to the individual speed data that was collected for the storm event on December 1st to December 2nd at milepost 273.15. It's clear from the Figure 9-3 the recommended speed limit from the Control Strategy and the observed speeds are following similar patterns. As the vehicles speeds dropped speed limits were also dropped indicating they are in compliance with each other. Whenever there is a huge difference between the recommended speed limit and the observed speeds it was observed that there were fewer vehicles traveling during that period. The speed compliance of vehicles following the *strict* definition of compliance increased from 33% to 62% with the new recommended speed limit in place; for vehicles following the *lenient* definition compliance increased from 64% to 79%.

Figure 9-4 plots the simulation results against the actual posted speed for the December 1-2, 2009 storm event. This figure illustrates that the draft control strategy recommends considerably more speed limit changes than those made under the manual protocol.

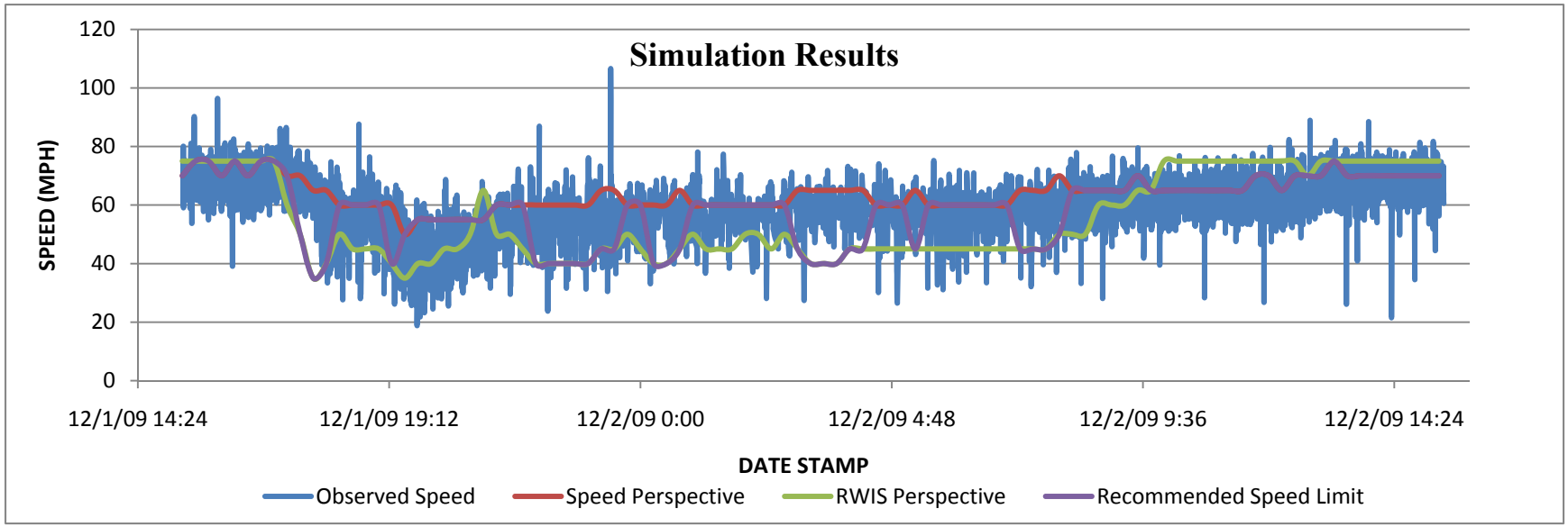

Figure 9-3: December Storm Event Simulation

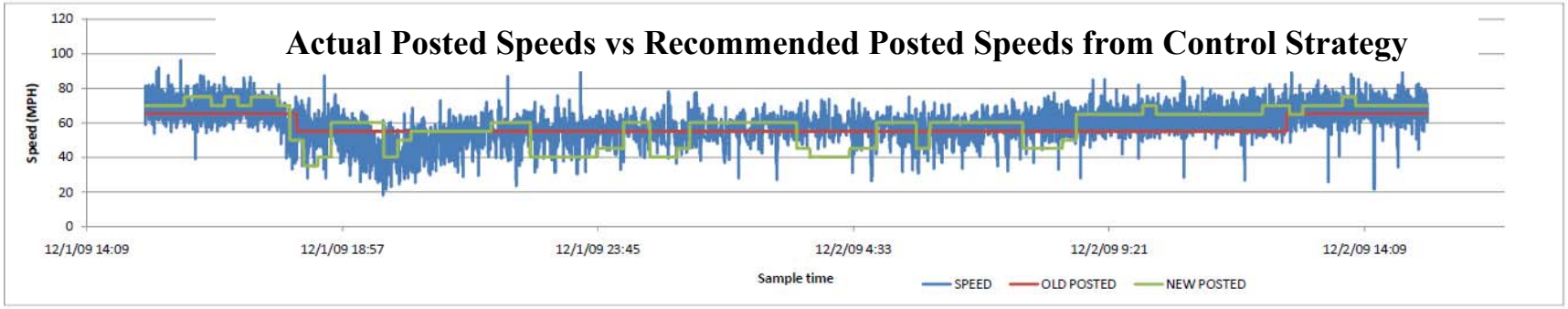

Figure 9-4: Comparison of Recommended Speeds and Actual Posted Speeds

9.3 Future Development of Control Strategy

The current control strategy is a draft version, so not all variables were used to in the methodology. More data for different time periods will be analyzed during the Phase II project to determine appropriate thresholds for all RWIS variables that were shown to be statistically significant. For the future control strategy more information about the RWIS variables will available from the new RWIS stations, which will help in getting thresholds of the significant variables more precisely. In depth analysis will be done to understand how much other speed sensors data is reliable in case any particular speed sensor malfunctions. A thorough analysis will be done on the trend followed by RWIS variables during the ideal and non ideal days to get the frequency and the duration of speed limit changes.

Chapter 10 Summary and Conclusions

This chapter will summarize and highlight the important aspects of the research tasks described in detail in previous chapters. The future research tasks for Phase II of the project will also be discussed.

10.1 DOT Surveys

State DOT surveys were completed to gain information about operating VSL systems in the U.S. From the survey that was sent to each state DOT, it was concluded that each system operates differently. Each state DOT operates their system in the way that benefits their state. The urban systems are monitoring incidents and speeds, whereas the majority of the rural systems are monitoring visibility, weather, and pavement conditions.

Each state has a different method of setting thresholds, which has resulted in a difference in the types of thresholds that have been established. Nine states are using LED signs, one is using VMS, and one is using Static Panel signs. Virginia is the only system that is automated. The other ten states require dispatch approval/verification before changing the speeds. Formal evaluations have not been completed on some of the corridors, but overall each DOT believes that the system is working on their corridors.

10.2 Crash Analysis

The overall goal of this project is to improve safety along the corridor as measured by the number of crashes that occur. Crash records for the first full year of VSL system operation were analyzed along with records for the years prior to the VSL system. Crash records must be analyzed for a minimum of three years with the system in operation in order to determine with statistical confidence if the safety along the corridor has

improved. Therefore, in the future, crash records will be analyzed to determine the effectiveness of the VSL system on improving safety. In the meantime, crash records prior to the VSL system installation were analyzed to set the baseline crash history.

Crash record data from 10 and 5 years prior to the VSL system installation showed persistent crash problems along the corridor. During the study it became clear, that corridor between Peterson (MP 238.15) and Quealy Dome (MP 290.44) is prone to higher crash rates than other parts of the I-80 WY. Approximately 2,600 crashes occurred on the VSL corridor between January 1, 2001 and April 15, 2010 and there were minimum 22 crashes recorded by WYDOT per each mile along the corridor. The study also found that West MP 252 remained an accident prone spot with 86 crashes, which is the highest number for the corridor.

Most important variables that lead to a crash were found to be weather and road conditions, since the majority of crashes accidents have happened during severe weather conditions or on the icy/frosty/wet pavement.

The year after VSL system was implemented in February 18, 2009 was the period when Elk Mountain Corridor had the fewest crashes of any of the 10 years prior. During this time the total number of incidents and the number of injury crashes fell to 0.999 and 0.208 per Million Vehicle Miles Traveled (MVMT) respectively. These are the lowest crash rates in the last decade. The highest total crash rate occurred between February 18, 2007 and February 17, 2008. However, the number of fatal crashes remained consistent in the last ten years and was equal to three fatal crashes per year on average.

10.3 System Implementation

The VSL system use was analyzed for two winter time periods and one summer time period for five VSL sign locations in each direction (EB and WB). Analyses compared the various posted speeds to the frequency, cumulative duration, and average duration of each use of that particular speed. Data was also broken down by milepost as different speeds were implemented in varying frequencies and durations along the corridor. There is a clear preference of the TMC to implement speeds of 65, 55, 45, and 35 mph as opposed to 60, 50, and 40 mph. The VSL system is widely used throughout the year with typically long durations.

Additional analyses were done for four newly added mileposts, two in the eastbound direction and two in the westbound direction. These analyses were completed for the winter season from 2009 to 2010, although the speed sensors came online beginning on February 3, 2010.

10.4 Baseline Speeds

Analyses were completed on driver's speeds during "ideal" and "non-ideal" conditions. Ideal conditions were described by dry roads and wind speeds less than 45 mph. Because of the seasonal speed limit, there were two sets of data for this phase, a 65 mph data set and a 75 mph data set.

One of the goals of the Variable Speed Limit system (VSL) is to decrease the speed variation between the vehicles. When there is a large difference in speeds between vehicles, there become safety problems. Overall, the speed variation decreased between the 75 mph data and the 65 mph data, which shows that decreasing the speed decreases the speed variation. It seems that during the 65 mph data set, the average and 85th

percentile speeds were much higher than the posted limit compared to the 75 mph data set. It seems like drivers were more disobedient of the seasonal 65 mph speed limit when the conditions were "ideal". The baseline speeds will likely become a modeling variable during Phase II.

10.5 RWIS Variable analysis

The Road Weather Information System (RWIS) records a number of weather variables. The task was to figure which variables were significant to use in future. The data was split up into four storm events since there were issues encountered with running larger data sets.

The time of day has an impact on driver's speeds. Drivers drive faster during the day than they do at night. Surface status (SfStatus) was significant in three out of the four models. Drivers speeds are faster when the surface is dry than when there is moisture on the road. Visibility was significant in both Storms 3 and 4. Wind speed is also a factor that impacts driver's speeds. Storm 4 was the only event in which neither wind gust speed (WindGustSpeed) or average wind speed (AvgWindSpeed) were significant. In all other storm events, either one or the other is significant.

The variables that were deemed as insignificant were the wind direction, the relative humidity (RH), the dewpoint, and the temperature variables. These were variables that even though they were often significant in the model are not variables that drivers appear to react to while they are driving.

Precipitation rate (PrecipRate) became a significant variable in the model that was run for a separate task to see if the VSL system was impacting driver's speeds. The

PrecipRate variable was not available in the earlier data set used to estimate the other models.

For the 2009 winter storm event from October 15th to December 15th the data was not divided into storm events. The RWIS variable analysis was done for the entire period as a single file. Surface status, surface temperature, RH and dew point were significant in impacting the speeds of the vehicles in both the directions. The visibility variable was least significant possibly because of units issues (visibility is in feet and other variables are measured in miles).

For the storm that occurred during December 1st to December 2nd 2009, individual speed data was collected and RWIS variable analysis was done. It was found that surface status and precipitation type variables have the most significant impact on vehicle speeds. The other RWIS variables: surface temperature, RH and dew point have become significant variables.

10.6 RWIS Significance

From the modeling, it was found that the single RWIS station currently installed on the corridor does a reasonable job at describing the conditions along the corridor. Just as every storm event is entirely different, storm events hit different locations to varying degrees.

In this task, all the speed sensors were compared to the control sensor. The control sensor was located at Arlington and was used because the RWIS station was located closest to that speed sensor. The majority of the variables from each sensor model matched the control sensor variables. In Sensors 16 through 19 wind gust speed (WindGustSpeed) was not a significant variable, and relative humidity (RH) and

Dewpoint were the other two that were common variables that did not match up with the control sensor. Even though the RWIS station does a reasonable job at describing the conditions along the corridor, it would be beneficial to have more RWIS stations along the corridor so that the weather conditions at each sensor are more accurately defined.

10.7 VSL Sign Significance

The initial model with both the eastbound (EB) and westbound (WB) variables found that the EB significance was much greater than the WB significance. Therefore, new models that split the speed sensor data by direction were run with separate variables to see what the significance was when each variable was modeled independently.

For winter 2009 modeling it was found that EB and WB variables have almost the same amount of impact on vehicle speeds. The coefficient of these variables varied from 0.587 to 0.857. These coefficients are interpreted as the VSL system impacting the observed speeds by lowering them 5.9 to 8.6 mph for every 10 mph of speed reduction posted on the signs. This observed speed reduction is in addition to the natural speed reductions due to observed weather conditions. It is clear from the results from the December storm event modeling that there was low speed compliance as the coefficient of EB and WB variables varied from 0.345 to 0.643.

Therefore, the VSL is impacting driver's speeds. This information is based off eight speed sensors and two months worth of data during the winter of 2009. Analysis must be done more extensively to see if this conclusion is consistent for all sensors along the corridor.

10.8 Individual Speed Analyses

To check how cars and trucks are reacting to VSL signs individual speed data was collected. Data was collected for the three mileposts 256.25, 273.15 and 289.5 for three different storm events occurring: December 1-2, 2009; February 3-4, 2010; and March 18-21, 2010. Collecting individual data requires sensors to be taken off-line from the program that runs the TMC speed map and therefore data from only three sensors was collected for limited time durations. The sensors selected to get observations from are at the beginning, middle, and end of the corridor. The original binned data does not give 85th percentile speeds; nor does it separate cars and trucks. The classification of vehicles was done based on the size of the vehicles. To examine the difference in speed behavior between cars and trucks the speed data was filtered into 5 minute and 15 minute periods. Graphs were drawn between 85th percentile speeds of cars, trucks and posted speed limits for two categories (5 minute and 15 minute).

In a similar way, to check for the speed deviation among cars and trucks, speed data was aggregated into 15 minute period and standard deviation was calculated. Graphs were drawn between standard deviations of cars and trucks. Statistical significance testing was done for both the difference in speeds and the difference in standard deviation for cars versus trucks. Statistical significance was found between car speeds and truck speeds. Cars were traveling faster than trucks. Statistical significance was also found between the standard deviations of cars and trucks for the February and March storm events, where cars had a higher standard deviation. For the December storm event there was no statistically significant difference between the standard deviation of cars and trucks. In depth analysis was done by categorizing the entire storm event into four stages:

Ideal, Transition, VSL implemented and Extended VSL. During these stages average speed, 85th percentile and standard deviation were found.

Speed compliance was defined for this analysis in two ways. The first was a *strict* definition that determined the percentage of vehicles that were observed going at or below the posted speed limit. The second was a more *lenient* definition where vehicles were considered compliant if they were going not more than 5 mph above the speed limit. The data was split into the way above mentioned. The results were shown that there was low speed compliance. Speed profiles were created to show vehicle speed versus the frequency of occurrence using the individual speed data in EB and WB directions. As predicted speeds were high during the ideal period then they begin to drop during the transition period. Speed variation was higher during the transition period compared to that of the VSL implemented period and speeds start to increase in the extended VSL period.

Data from a summer and winter ideal time period was analyzed to demonstrate how drivers have been reacting to the 65 mph seasonal speed limit. An ideal time period is one that occurs prior to a storm event; the VSL has not been implemented, and is during daylight hours. The maximum speed limit is in place during ideal periods, so the winter speed limit was 65 mph and the summer speed limit was 75 mph. The analyses from the ideal data sets demonstrated that during ideal periods cars typically drive faster than trucks. Also, it was found that the 85th percentile speeds of vehicles in the summer and winter period were nearly the same, only a 1.5 mph difference, even though there was a 10 mph difference in the speed limit. Furthermore, the speed compliance rates were much higher during the summer period than they were during the winter period.

10.9 Draft Control Strategy

To improve the efficiency of current VSL system on Elk Mountain corridor a draft model of control logic was designed. Control logic is a step by step procedure that allows the TMC operator to post speed limits that are timely and reasonable based on real time weather and speed data instead of relying on personnel in the field to initiate the change. The intention is not to fully automate the process. Therefore, verification of conditions and authorization of the recommended speed limits would still be done by TMC operators.

Development of draft VSL control strategy was done by analyzing the data that was collected from the October to December, 2009 time period and the individual speed data for the December 1-2, 2009 storm event. The data was categorized into 9 different bins based on observed speed and then sub categorized based on surface status and precipitation type. To observe the trend between the observed speeds and the candidate RWIS variables, graphs were drawn. Thresholds of RWIS variables that are statistically significant and following the same trend as of observed speeds are found by analyzing maximum, minimum, average and 85th percentile values.

The draft control logic was implemented in two stages:

1. Observed speed perspective, and
2. Weather variable perspective

In stage 1 the data which was merged from speed sensor data, RWIS data and VSL data will pass through quality checks. The 85th percentile speeds and the vehicle counts for every fifteen minute period were calculated. The data will pass through low volume filter and speed rounding filter resulting in a new suggested posted speed limits.

During stage 2 the data, after merging and passing through quality checks, passes through 9 sub threshold filters. The data which bypasses those sub filters will pass through visibility threshold filter, this filter will ensure that there is no missing data. 85th percentiles were calculated every fifteen minute period for the data that passed through all the filters. New recommended speed limits were obtained by applying the speed rounding filter to the 85th percentiles.

After obtaining the speed limits from both the speed and RWIS methodologies, the data should pass through a final filter which combines the two recommendations (if different). The Final filter:

- If the difference between speeds obtained from the RWIS perspective and speed perspective is greater than 15 mph then the RWIS limit should be used; otherwise the speed perspective limits (Stage 1) are used.

10.10 Phase II Project

Research on the variable speed limit corridor with a 30-month Phase II project will continue to monitor the implementation of a control strategy and decision-support system on the Elk Mountain VSL corridor. The Phase II project will also look at four proposed VSL corridors in other parts of the state. The four proposed VSL corridors are listed below.

- I-80 between Green River and Rock Springs (MP 88 – 111). This project is expected to be let for bid in Spring 2010 and constructed by Fall 2010.
- I-80 between Laramie and Cheyenne (MP 316 – 356). This project is expected to be let for bid in Fall 2010 and constructed by Fall 2011.
- I-80 east of Evanston through the Three Sisters corridor (MP 7-28). This project is expected to be let for bid on Fall 2010 and constructed by Fall 2011.

- US 287 from Tie Siding to the State Line (MP 420 to 426). This project is expected to be let for bid on Spring 2013 and constructed by Fall 2014.

The work plan for the Phase II project is divided into the following 10 tasks.

1. Procurement and installation of speed sensors and RWIS for US 287 Corridor.
2. Compilation and characterization of historical weather data for the Green River–Rock Springs, Cheyenne–Laramie, and Evanston–Three Sisters Corridors.
3. Generation of baseline speeds in the corridor and determination of existing speed response to weather conditions for the Green River–Rock Springs, Cheyenne–Laramie, and Evanston–Three Sisters Corridors.
4. Development of Decision-Support Systems for the Green River–Rock Springs, Cheyenne–Laramie, and Evanston–Three Sisters Corridors.
5. Implementation of the Decision-Support Systems for the Green River–Rock Springs, Cheyenne–Laramie, and Evanston–Three Sisters Corridors.
6. Compilation and characterization of historical weather data for the US 287 Corridor
7. Generation of baseline speeds in the corridor and determination of existing speed response to weather conditions for the US 287 Corridor.
8. Monitoring of the Implemented Use of the Decision-Support Systems and Modifications as Necessary.
9. Development of Decision-Support System for US 287 Corridor.
10. Development of Generalized Methodology for Decision-Support Systems for Future Corridors.

Results from the Phase I project for the Elk Mountain VSL Corridor indicate that a decision support system to recommend speed limit changes is required to get necessary levels of speed compliance and reductions in speed variations. As the number of VSL systems in

Wyoming increase, this need becomes even more important as operators at the WYDOT's Traffic Management Center (TMC) become responsible for a larger number of VSL signs. The second phase of this research proposes to study baseline conditions for weather and speeds for each of the proposed VSL corridors in order to develop a decision support system for each corridor. corridor. There are significant differences in the types of travelers, roadway variables, and weather on each of the corridors that warrant further research beyond the Phase I project. It is hoped from the second phase of this research that a general methodology for operations of all future VSL systems could be developed.

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Appendix A

State DOT Surveys

Variable Speed Limit Survey

The University of Wyoming is working on a Variable Speed Limit System for the Wyoming Department of Transportation. As part of this effort, we are contacting other state DOTs to see if they have implemented any VSLs in their state. Answering the following questions is greatly appreciated.

1. What State are you responding for?
2. Are you using a Variable Speed Limit system in your state? (If yes, please continue. If no, thank you for your participation.)
3. What corridors are you using the Variable Speed Limit system on? (Please provide the Route and the approximate mileposts)
4. How many signs do you have on the corridor? What type of signs are they?
5. Are you using the Variable Speed Limits in a rural or urban setting?
6. What real-time variables are you taking into consideration (ex: vehicle speeds, weather conditions, etc)?
7. Do you feel that your Variable Speed Limit system is working on the corridor?

Thank you for your time in completing this survey. If you have any questions about our effort please contact:

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Variable Speed Limit Survey

The University of Wyoming is working on a Variable Speed Limit System for the Wyoming Department of Transportation. As part of this effort, we are contacting each DOT with a VSL system to learn more about each one. Answering the following questions is greatly appreciated.

1. What State are you responding for?
2. What specific [weather] and [speed] variables are being monitored?
3. Are there threshold levels associated with these variables related to implementing variable speeds? If so, what are these thresholds?
4. Is dispatcher approval/verification necessary before the system is activated?
5. Are your signs overhead or side-mounted?
6. Have any formal evaluations on the effectiveness of the system been performed? If so, is a copy available?

Thank you for your time in completing this survey. If you have any questions about our effort please contact:

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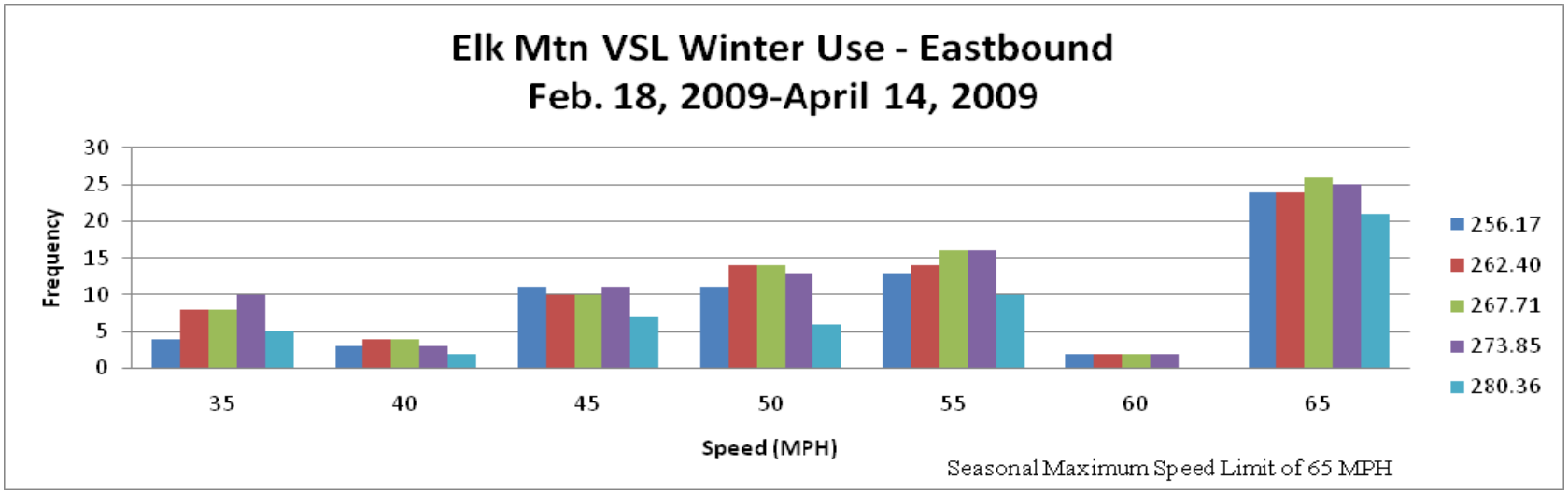
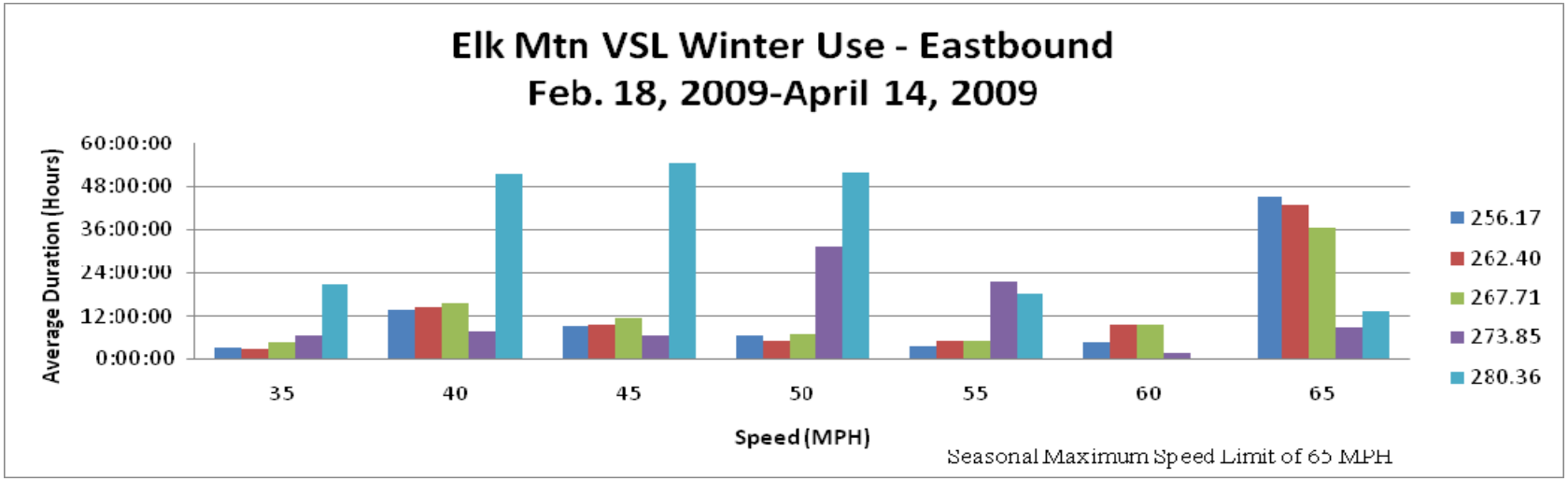
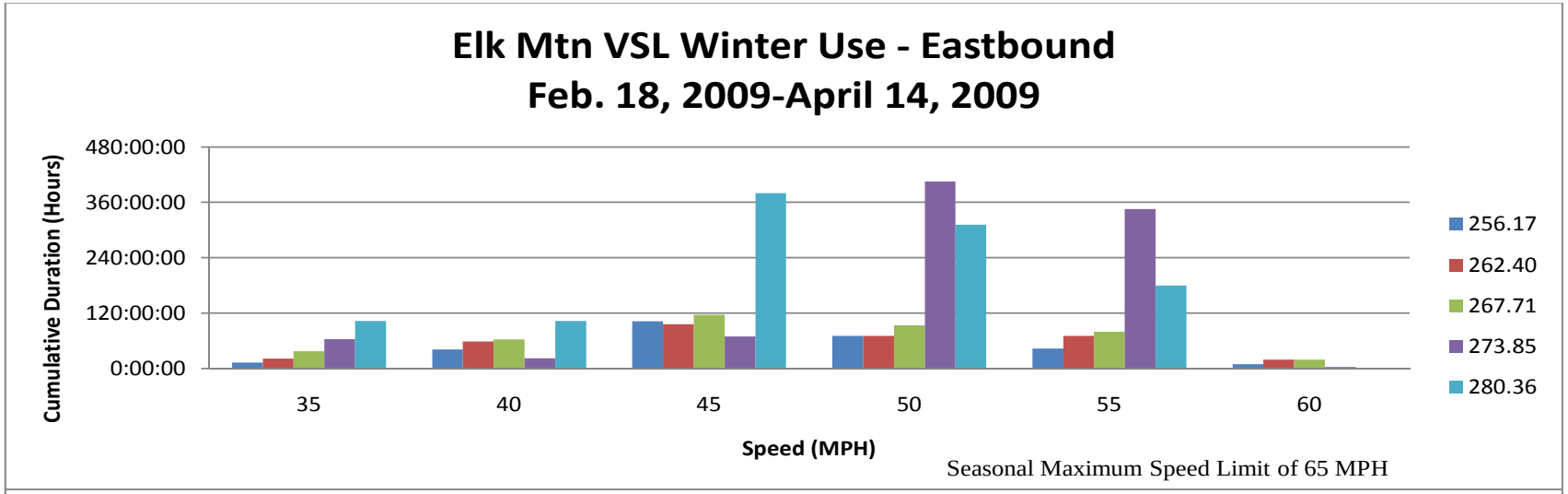
Appendix B

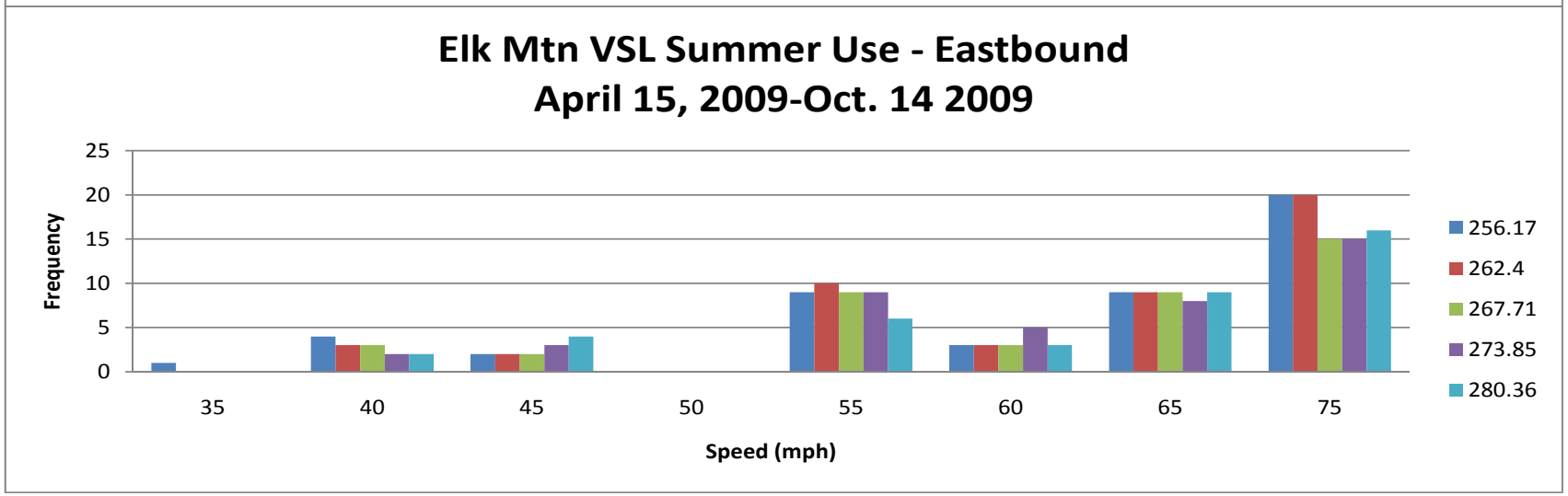
VSL Use Charts

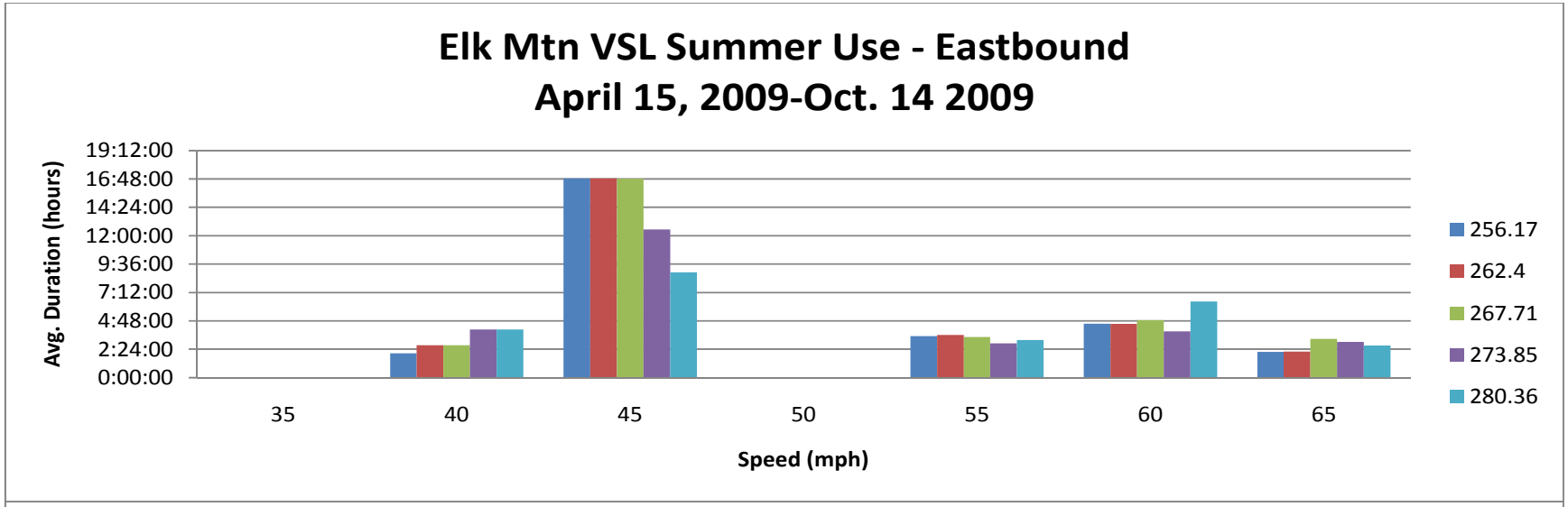

Elk Mtn VSL Winter Use - Eastbound
Feb. 18, 2009-April 14, 2009
Frequency
30
25
20
15
10
5
0
35
40
45
50
55
60
65
Speed (MPH)
256.17
262.40
267.71
273.85
280.36
Seasonal Maximum Speed Limit of 65 MPH

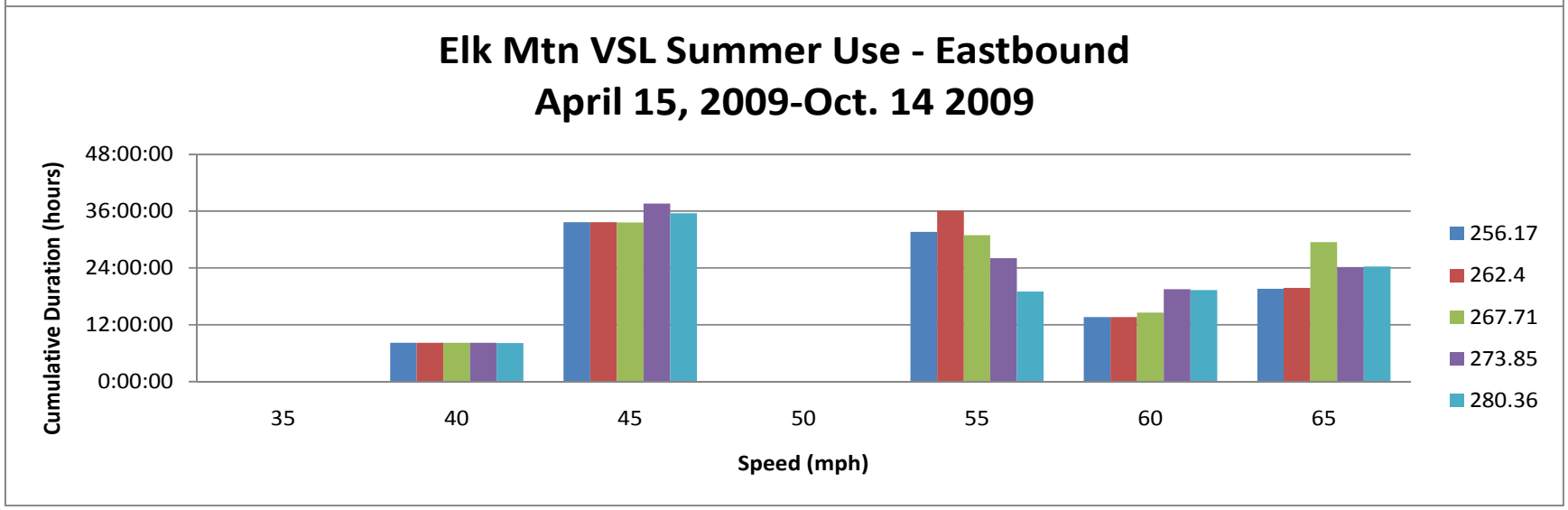

Elk Mtn VSL Winter Use - Eastbound
Feb. 18, 2009-April 14, 2009
Average Duration (Hours)
60:00:00
48:00:00
36:00:00
24:00:00
12:00:00
0:00:00
35
40
45
50
55
60
65
Speed (MPH)
256.17
262.40
267.71
273.85
280.36
Seasonal Maximum Speed Limit of 65 MPH

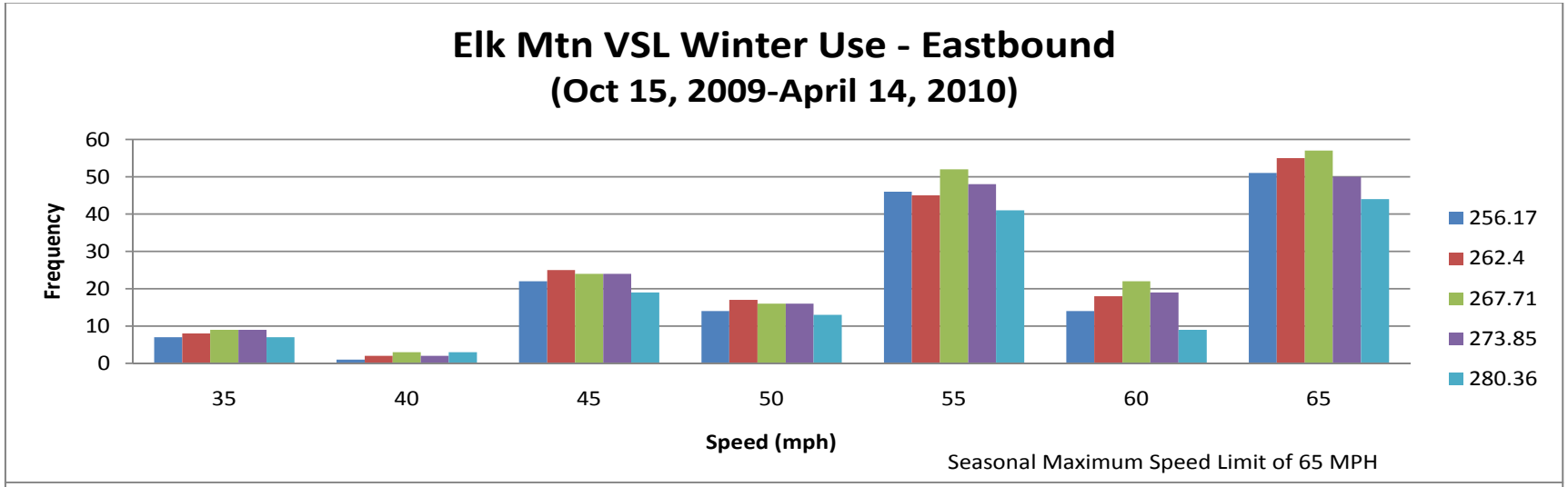


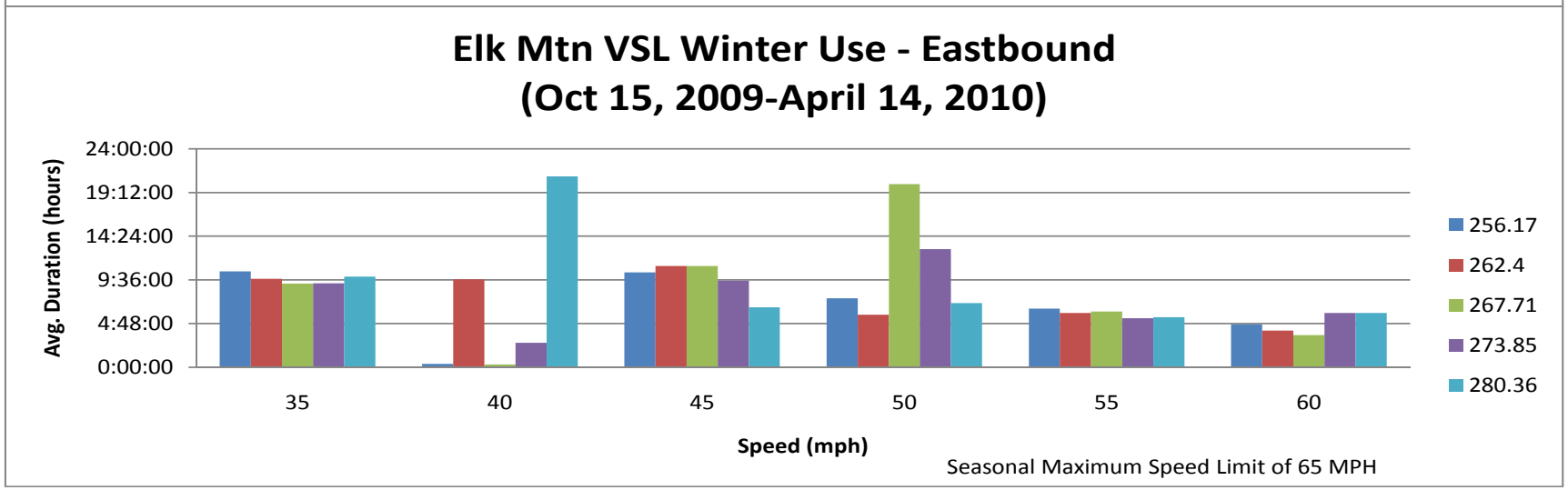
Seasonal Maximum Speed Limit of 65 MPH

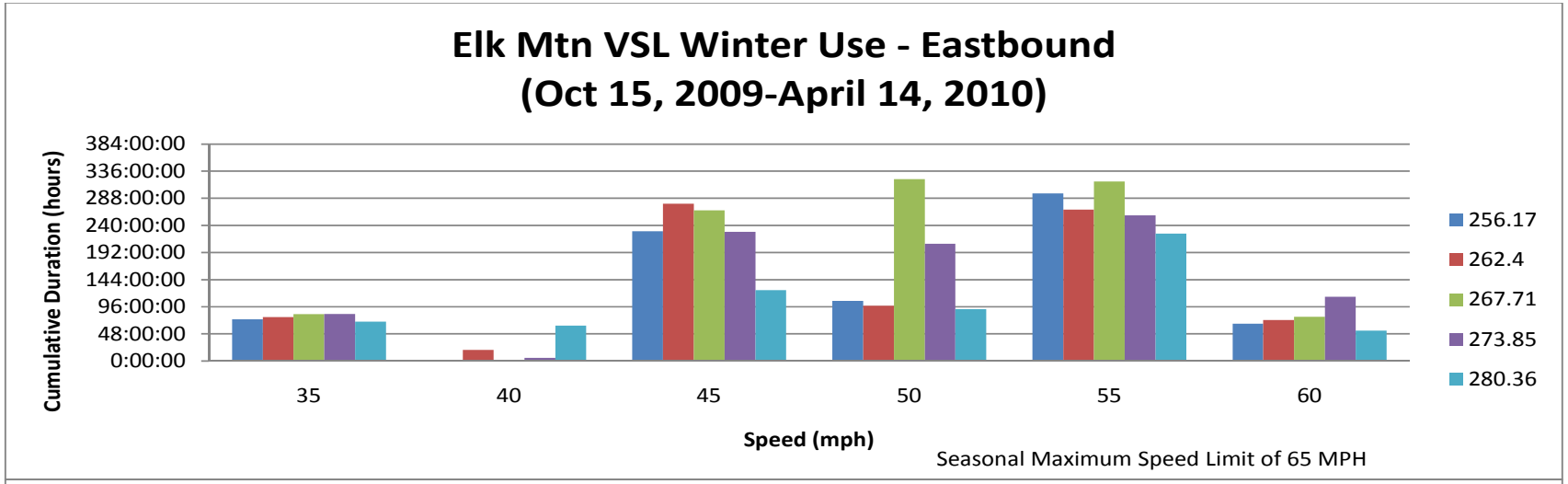


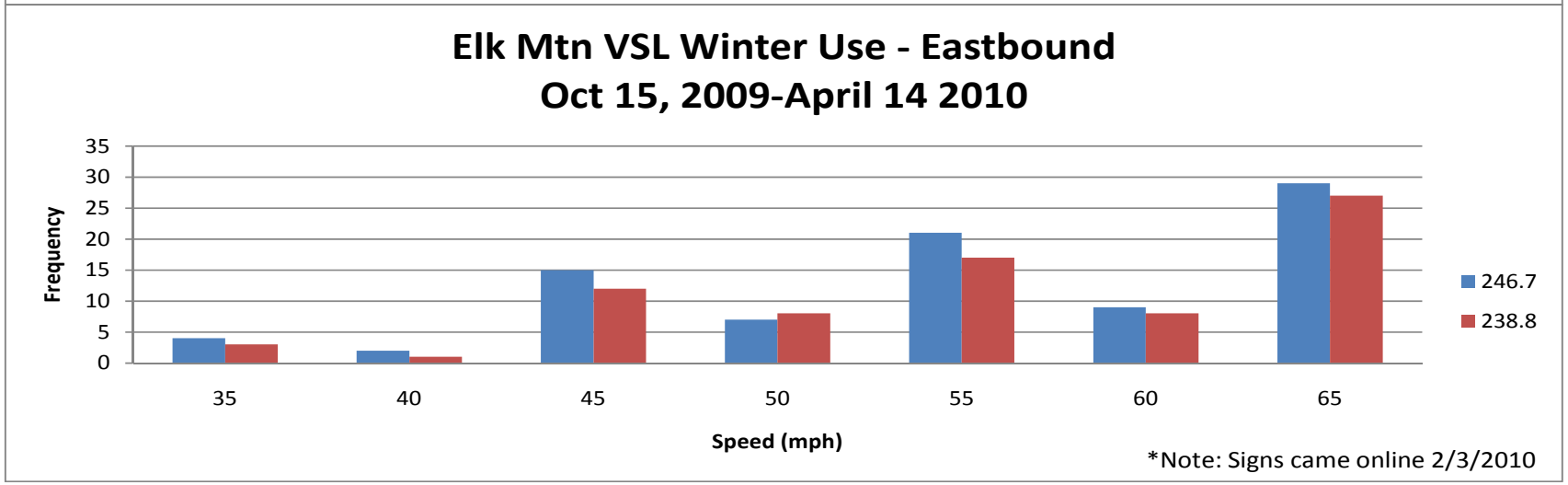

Elk Mtn VSL Summer Use - Eastbound
April 15, 2009-Oct. 14 2009
Avg. Duration (hours)
19:12:00
16:48:00
14:24:00
12:00:00
9:36:00
7:12:00
4:48:00
2:24:00
0:00:00
35
40
45
50
55
60
65
Speed (mph)
256.17
262.4
267.71
273.85
280.36

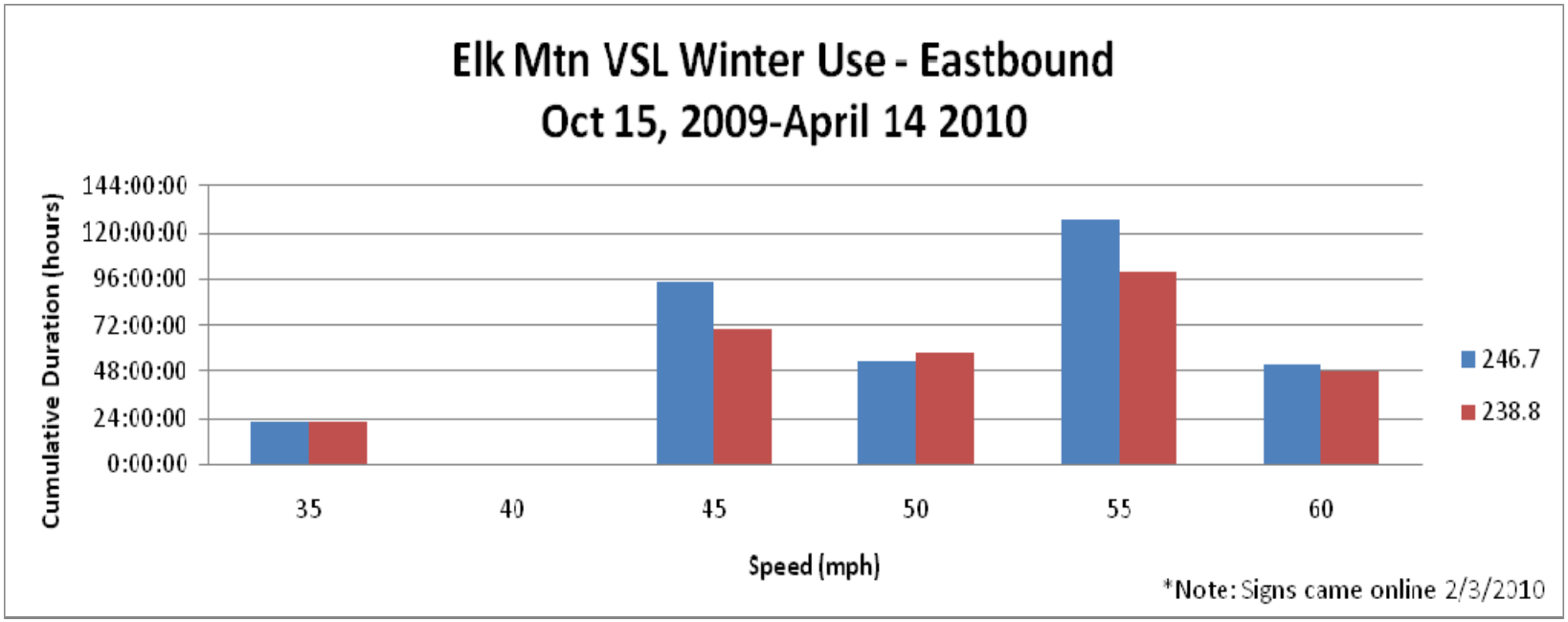

Elk Mtn VSL Summer Use - Eastbound
April 15, 2009-Oct. 14 2009
Cumulative Duration (hours)
48:00:00
36:00:00
24:00:00
12:00:00
0:00:00
35
40
45
50
55
60
65
Speed (mph)
256.17
262.4
267.71
273.85
280.36


Elk Mtn VSL Winter Use - Eastbound
(Oct 15, 2009-April 14, 2010)
Frequency
60
50
40
30
20
10
0
35
40
45
50
55
60
65
Speed (mph)
256.17
262.4
267.71
273.85
280.36
Seasonal Maximum Speed Limit of 65 MPH


Elk Mtn VSL Winter Use - Eastbound
(Oct 15, 2009-April 14, 2010)
Avg. Duration (hours)
24:00:00
19:12:00
14:24:00
9:36:00
4:48:00
0:00:00
35
40
45
50
55
60
Speed (mph)
256.17
262.4
267.71
273.85
280.36
Seasonal Maximum Speed Limit of 65 MPH


Elk Mtn VSL Winter Use - Eastbound
(Oct 15, 2009-April 14, 2010)
Cumulative Duration (hours)
384:00:00
336:00:00
288:00:00
240:00:00
192:00:00
144:00:00
96:00:00
48:00:00
0:00:00
35
40
45
50
55
60
Speed (mph)
256.17
262.4
267.71
273.85
280.36
Seasonal Maximum Speed Limit of 65 MPH


Elk Mtn VSL Winter Use - Eastbound
Oct 15, 2009-April 14 2010
Frequency
35
30
25
20
15
10
5
0
35
40
45
50
55
60
65
Speed (mph)
246.7
238.8
*Note: Signs came online 2/3/2010


Elk Mtn VSL Winter Use - Eastbound
Oct 15, 2009-April 14 2010
Cumulative Duration (hours)
144:00:00
120:00:00
96:00:00
72:00:00
48:00:00
24:00:00
0:00:00
35
40
45
50
55
60
Speed (mph)
246.7
238.8
*Note: Signs came online 2/3/2010

Appendix C

SAS Statistical Output

Storm 1 First Model

The SAS System 12:06 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	22272
Number of Observations Used	19324
Number of Observations with Missing Values	2948

Analysis of Variance

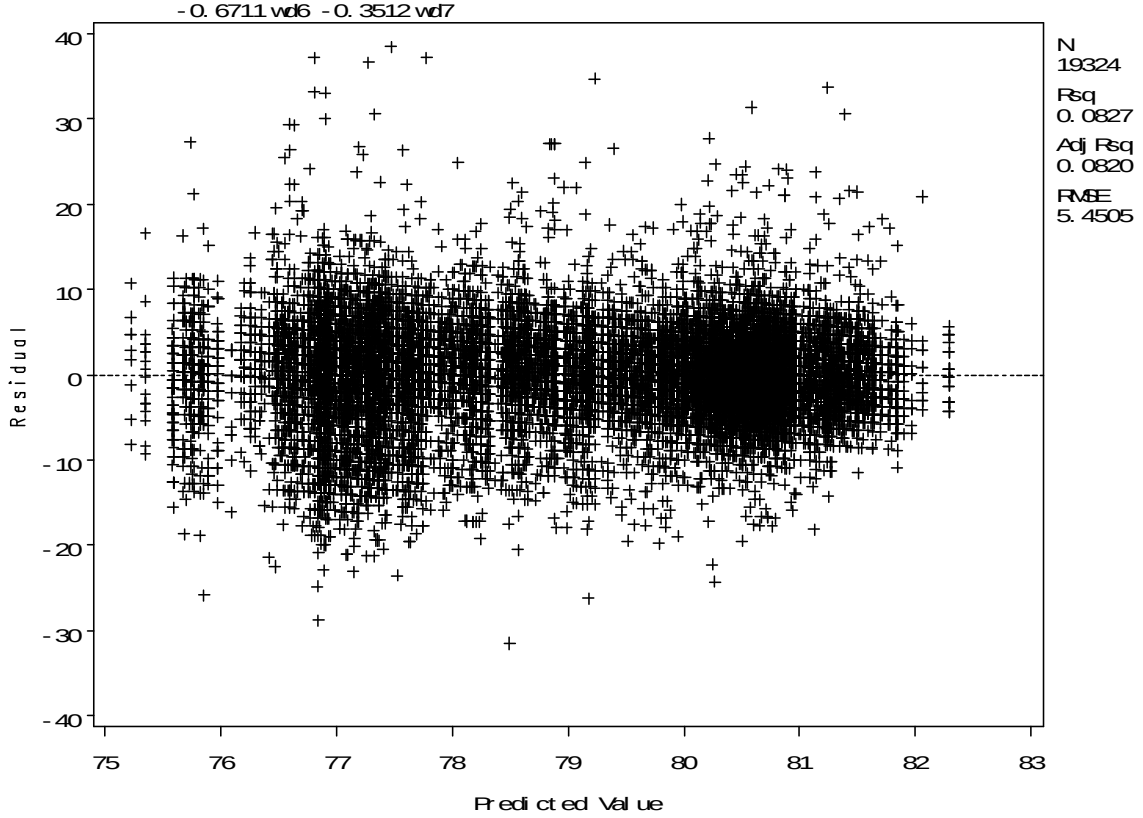
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	16	51723	3232.71221	108.82	<.0001
Error	19307	573565	29.70761		
Corrected Total	19323	625288			

Root MSE	5.45047	R-Square	0.0827
Dependent Mean	79.18852	Adj R-Sq	0.0820
Coeff Var	6.88290		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	85.86753	2.08905	41.10	<.0001	0
SfStatus	SfStatus	1	1.20988	0.23862	5.07	<.0001	1.12870
SfTemp	SfTemp	1	0.03685	0.00661	5.57	<.0001	8.77734
SubTemp	SubTemp	1	-0.07994	0.02907	-2.75	0.0060	2.00730
AvgWindSpeed	AvgWindSpeed	1	0.01563	0.01974	0.79	0.4285	11.73516
GustWindSpeed	GustWindSpeed	1	-0.02892	0.01416	-2.04	0.0411	13.23910
AirTemp	AirTemp	1	-0.09663	0.01981	-4.88	<.0001	19.31725
RH	RH	1	-0.06629	0.00738	-8.99	<.0001	25.65473
Dewpoint	Dewpoint	1	0.10076	0.01690	5.96	<.0001	11.85603
Day_Night	Day_Night	1	1.82396	0.13464	13.55	<.0001	2.80860
wd1		1	0.39295	0.27396	1.43	0.1515	1.72547
wd2		1	-0.14652	0.21362	-0.69	0.4928	3.29313
wd3		1	-0.28485	0.24750	-1.15	0.2498	2.17921
wd4		1	0.20492	0.36437	0.56	0.5739	1.33720
wd5		1	0.02201	0.33347	0.07	0.9474	1.43756
wd6		1	-0.67106	0.21276	-3.15	0.0016	4.76422
wd7		1	-0.35118	0.20488	-1.71	0.0865	6.82391

AvgSpeed85 = 85.868 +1.2099 SfStatus +0.0369 SfTemp -0.0799 SubTemp +0.0156 AvgWndSpeed
-0.0289 GustWndSpeed -0.0966 AirTemp -0.0663 RH +0.1008 Dewpoint
+1.824 Day_Night +0.3929 wd1 -0.1465 wd2 -0.2849 wd3 +0.2049 wd4 +0.022 wd5
-0.6711 wd6 -0.3512 wd7



Storm 1 Final Model

The SAS System 12:06 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	22272
Number of Observations Used	19324
Number of Observations with Missing Values	2948

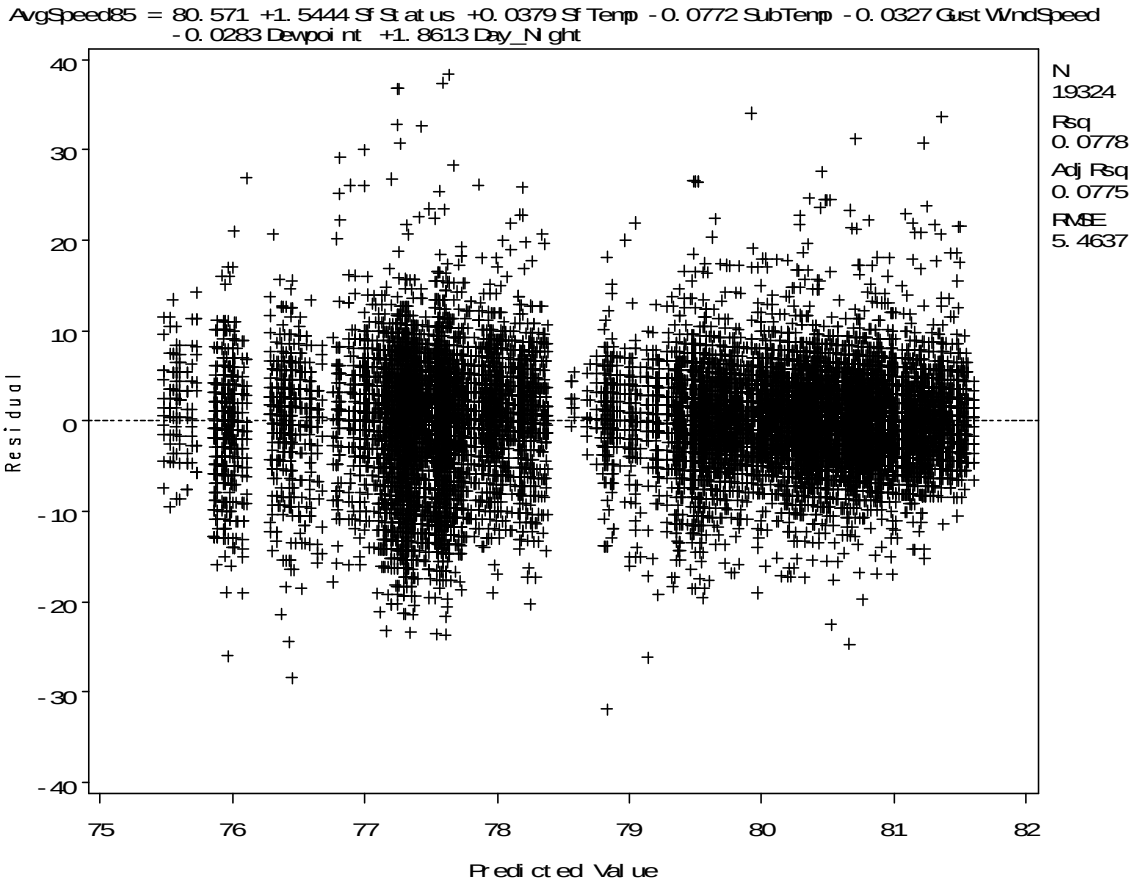
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	48639	8106.46571	271.56	<.0001
Error	19317	576649	29.85191		
Corrected Total	19323	625288			

Root MSE	5.46369	R-Square	0.0778
Dependent Mean	79.18852	Adj R-Sq	0.0775
Coeff Var	6.89960		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	80.57061	1.98363	40.62	<.0001	0
SfStatus	SfStatus	1	1.54445	0.23236	6.65	<.0001	1.06501
SfTemp	SfTemp	1	0.03795	0.00358	10.61	<.0001	2.55557
SubTemp	SubTemp	1	-0.07723	0.02715	-2.84	0.0045	1.74296
GustWindSpeed	GustWindSpeed	1	-0.03269	0.00505	-6.47	<.0001	1.67878
Dewpoint	Dewpoint	1	-0.02825	0.00784	-3.60	0.0003	2.54232
Day_Night	Day_Night	1	1.86134	0.12780	14.56	<.0001	2.51810


AvgSpeed85 = 80.571 +1.5444 SfStatus +0.0379 SfTemp -0.0772 SubTemp -0.0327 GustWindSpeed
-0.0283 Dewpoint +1.8613 Day_Night
N
19324
Rsq
0.0778
Adj Rsq
0.0775
RMSE
5.4637
Residual
Predicted Value
40
30
20
10
0
-10
-20
-30
-40
75
76
77
78
79
80
81
82

Storm 1 Minus Outliers Initial Model

The SAS System 12:21 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	22272
Number of Observations Used	19324
Number of Observations with Missing Values	2948

Analysis of Variance

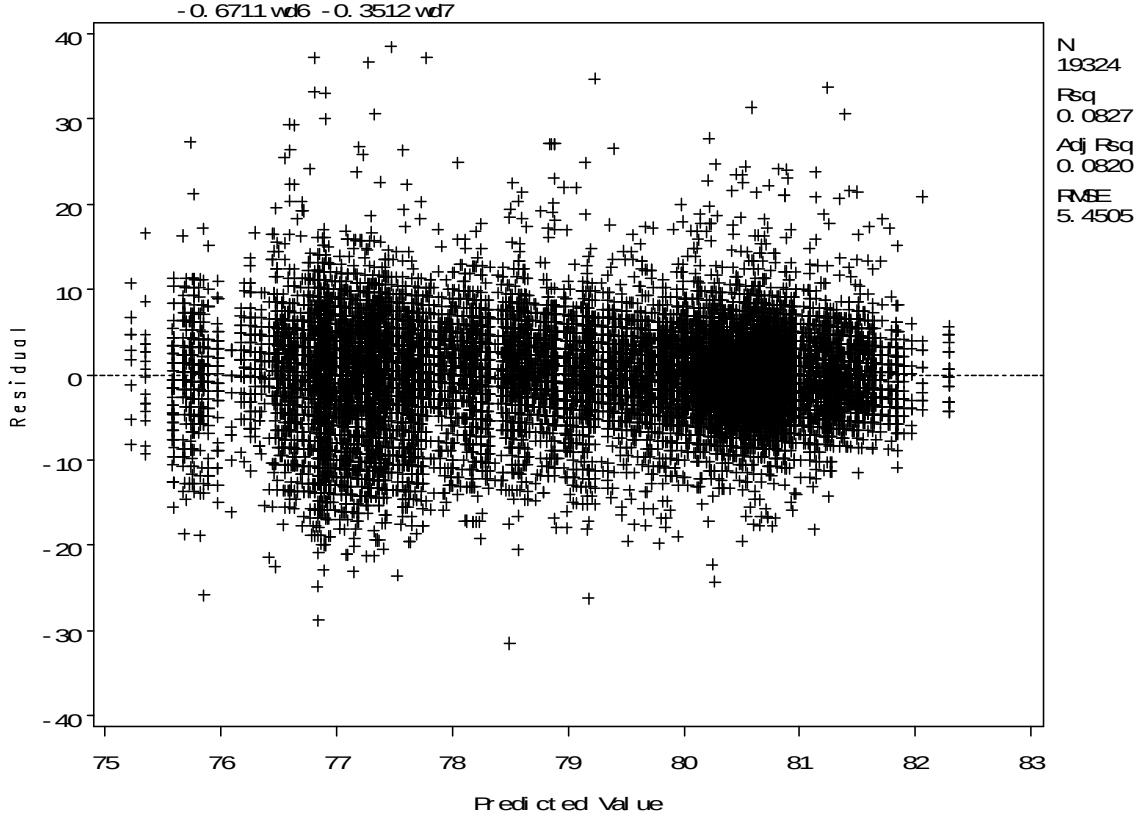
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	16	51723	3232.71221	108.82	<.0001
Error	19307	573565	29.70761		
Corrected Total	19323	625288			

Root MSE	5.45047	R-Square	0.0827
Dependent Mean	79.18852	Adj R-Sq	0.0820
Coeff Var	6.88290		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	85.86753	2.08905	41.10	<.0001	0
SfStatus	SfStatus	1	1.20988	0.23862	5.07	<.0001	1.12870
SfTemp	SfTemp	1	0.03685	0.00661	5.57	<.0001	8.77734
SubTemp	SubTemp	1	-0.07994	0.02907	-2.75	0.0060	2.00730
AvgWindSpeed	AvgWindSpeed	1	0.01563	0.01974	0.79	0.4285	11.73516
GustWindSpeed	GustWindSpeed	1	-0.02892	0.01416	-2.04	0.0411	13.23910
AirTemp	AirTemp	1	-0.09663	0.01981	-4.88	<.0001	19.31725
RH	RH	1	-0.06629	0.00738	-8.99	<.0001	25.65473
Dewpoint	Dewpoint	1	0.10076	0.01690	5.96	<.0001	11.85603
Day_Night	Day_Night	1	1.82396	0.13464	13.55	<.0001	2.80860
wd1		1	0.39295	0.27396	1.43	0.1515	1.72547
wd2		1	-0.14652	0.21362	-0.69	0.4928	3.29313
wd3		1	-0.28485	0.24750	-1.15	0.2498	2.17921
wd4		1	0.20492	0.36437	0.56	0.5739	1.33720
wd5		1	0.02201	0.33347	0.07	0.9474	1.43756
wd6		1	-0.67106	0.21276	-3.15	0.0016	4.76422
wd7		1	-0.35118	0.20488	-1.71	0.0865	6.82391

AvgSpeed85 = 85.868 +1.2099 SfStatus +0.0369 SfTemp -0.0799 SubTemp +0.0156 AvgWndSpeed
-0.0289 GustWndSpeed -0.0966 AirTemp -0.0663 RH +0.1008 Dewpoint
+1.824 Day_Night +0.3929 wd1 -0.1465 wd2 -0.2849 wd3 +0.2049 wd4 +0.022 wd5
-0.6711 wd6 -0.3512 wd7



Storm 1 Minus Outliers Final Model

The SAS System 12:21 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	22272
Number of Observations Used	19324
Number of Observations with Missing Values	2948

Analysis of Variance

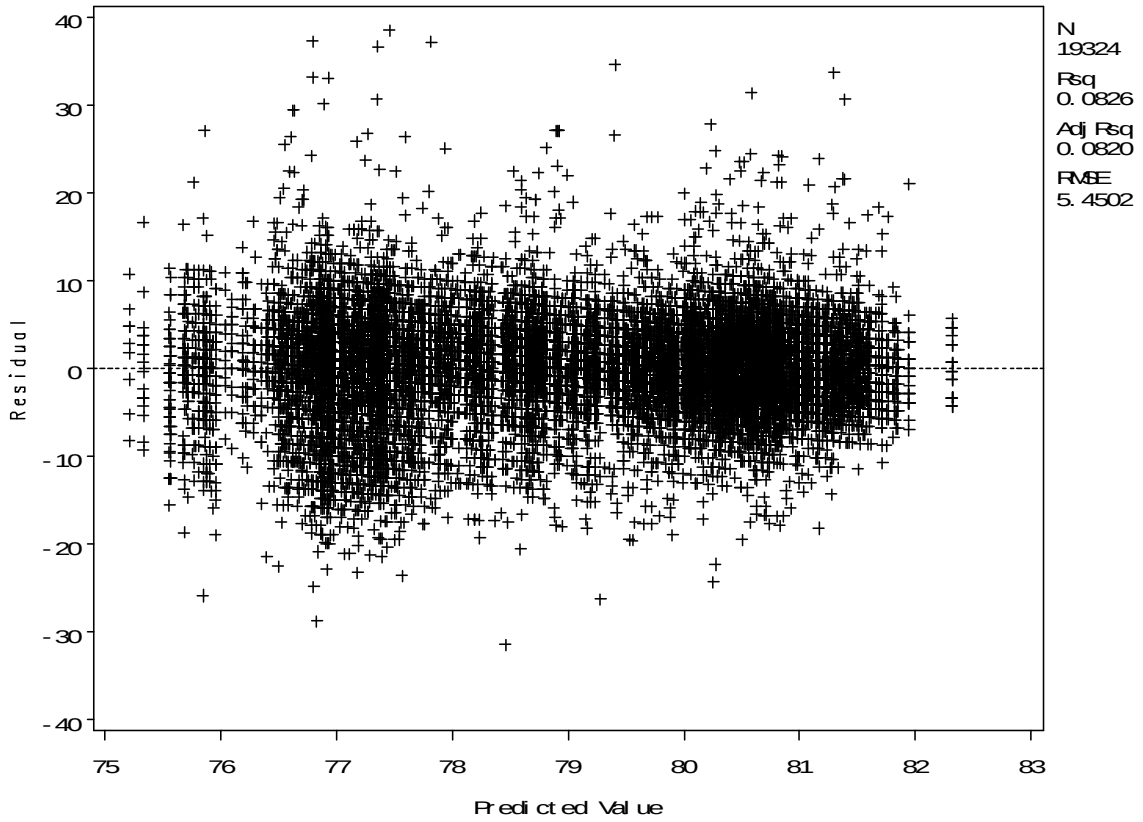
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	51629	4693.53344	158.01	<.0001
Error	19312	573659	29.70481		
Corrected Total	19323	625288			

Root MSE	5.45021	R-Square	0.0826
Dependent Mean	79.18852	Adj R-Sq	0.0820
Coeff Var	6.88258		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	85.80084	2.05966	41.66	<.0001	0
SfStatus	SfStatus	1	1.24978	0.23725	5.27	<.0001	1.11587
SfTemp	SfTemp	1	0.03597	0.00659	5.46	<.0001	8.71595
SubTemp	SubTemp	1	-0.08143	0.02890	-2.82	0.0048	1.98417
GustWindSpeed	GustWindSpeed	1	-0.01892	0.00595	-3.18	0.0015	2.33569
AirTemp	AirTemp	1	-0.09524	0.01970	-4.84	<.0001	19.09526
RH	RH	1	-0.06530	0.00722	-9.05	<.0001	24.56574
Dewpoint	Dewpoint	1	0.09822	0.01673	5.87	<.0001	11.62134
Day_Night	Day_Night	1	1.81766	0.13389	13.58	<.0001	2.77748
wd1		1	0.49490	0.21943	2.26	0.0241	1.10707
wd6		1	-0.55709	0.13221	-4.21	<.0001	1.83971
wd7		1	-0.22569	0.12193	-1.85	0.0642	2.41724

AvgSpeed85 = 85.801 +1.2498 SfStatus +0.036 SfTemp -0.0814 SubTemp -0.0189 GustWndSpeed
-0.0952 AirTemp -0.0653 RH +0.0982 Dewpoint +1.8177 Day_Night +0.4949 wd1
-0.5571 wd6 -0.2257 wd7



Storm 2 Initial Model

The SAS System 12:26 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	37196
Number of Observations Used	34601
Number of Observations with Missing Values	2595

Analysis of Variance

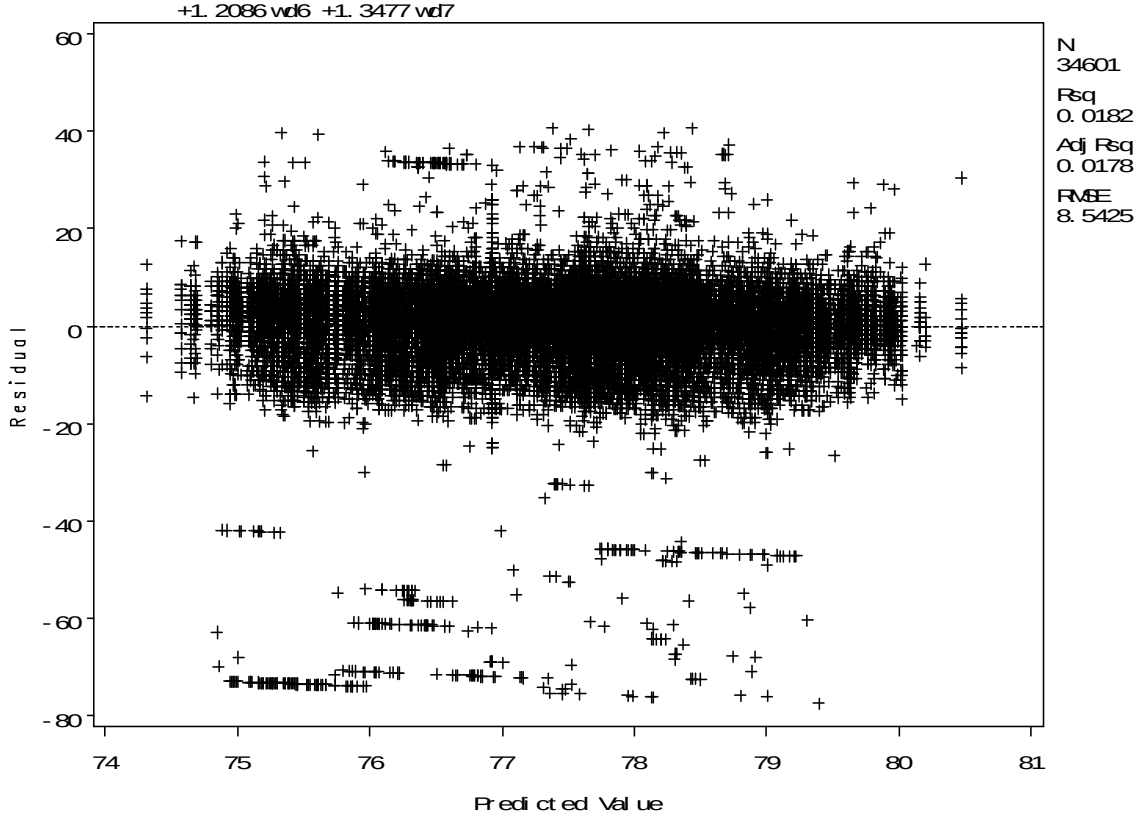
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	16	46889	2930.58025	40.16	<.0001
Error	34584	2523742	72.97428		
Corrected Total	34600	2570632			

Root MSE	8.54250	R-Square	0.0182
Dependent Mean	77.49623	Adj R-Sq	0.0178
Coeff Var	11.02312		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	50.28397	1.69332	29.70	<.0001	0
SfStatus	SfStatus	1	1.46749	0.26104	5.62	<.0001	1.49507
SfTemp	SfTemp	1	-0.02398	0.00858	-2.79	0.0052	9.15904
SubTemp	SubTemp	1	0.36733	0.03064	11.99	<.0001	2.97541
AvgWindSpeed	AvgWindSpeed	1	0.01002	0.02161	0.46	0.6429	12.64229
GustWindSpeed	GustWindSpeed	1	-0.03562	0.01636	-2.18	0.0295	13.93038
AirTemp	AirTemp	1	0.05155	0.01800	2.86	0.0042	11.24784
RH	RH	1	0.01322	0.00446	2.96	0.0031	6.34720
Dewpoint	Dewpoint	1	-0.01906	0.00673	-2.83	0.0046	4.67931
Day_Night	Day_Night	1	1.51037	0.14604	10.34	<.0001	2.50889
wd1		1	0.92166	0.68290	1.35	0.1771	1.51050
wd2		1	1.08485	0.46068	2.35	0.0185	4.22628
wd3		1	1.57588	0.45635	3.45	0.0006	4.70576
wd4		1	1.56617	0.49998	3.13	0.0017	2.87281
wd5		1	1.66759	0.46355	3.60	0.0003	3.97193
wd6		1	1.20862	0.41537	2.91	0.0036	20.40790
wd7		1	1.34766	0.41624	3.24	0.0012	17.15512

AvgSpeed85 = 50.284 +1.4675 SfStatus -0.024 SfTemp +0.3673 SubTemp +0.01 AvgWndSpeed
-0.0356 GustWndSpeed +0.0516 AirTemp +0.0132 RH -0.0191 Dewpoint
+1.5104 Day_Night +0.9217 wd1 +1.0849 wd2 +1.5759 wd3 +1.5662 wd4 +1.6676 wd5
+1.2086 wd6 +1.3477 wd7



Storm 2 Final Model

The SAS System 12:26 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	37196
Number of Observations Used	34601
Number of Observations with Missing Values	2595

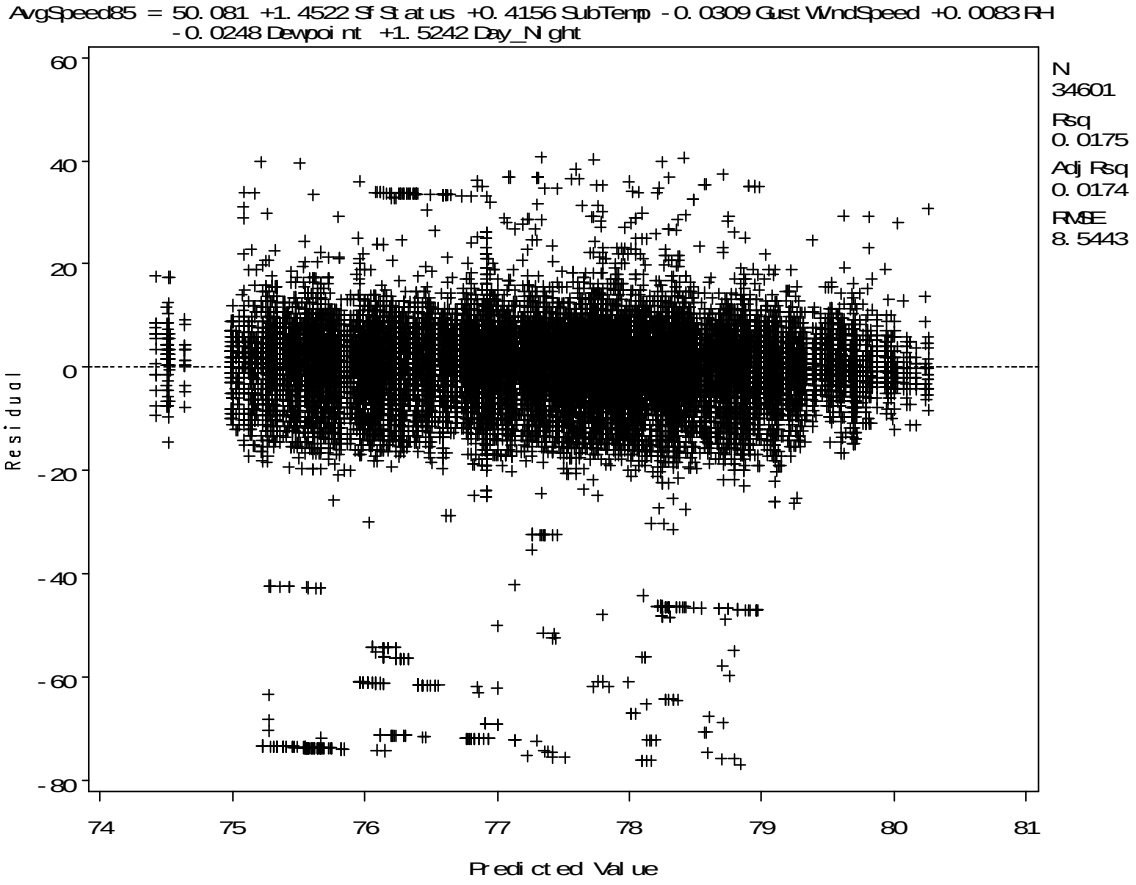
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	45092	7515.39138	102.94	<.0001
Error	34594	2525539	73.00513		
Corrected Total	34600	2570632			

Root MSE	8.54430	R-Square	0.0175
Dependent Mean	77.49623	Adj R-Sq	0.0174
Coeff Var	11.02544		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	50.08072	1.56377	32.03	<.0001	0
SfStatus	SfStatus	1	1.45216	0.25745	5.64	<.0001	1.45362
SubTemp	SubTemp	1	0.41564	0.02280	18.23	<.0001	1.64751
GustWindSpeed	GustWindSpeed	1	-0.03085	0.00548	-5.63	<.0001	1.55947
RH	RH	1	0.00831	0.00285	2.91	0.0036	2.59081
Dewpoint	Dewpoint	1	-0.02484	0.00497	-5.00	<.0001	2.54831
Day_Night	Day_Night	1	1.52422	0.10558	14.44	<.0001	1.31081


AvgSpeed85 = 50.081 +1.4522 SfStatus +0.4156 SubTemp -0.0309 GustWndSpeed +0.0083 RH
-0.0248 Dewpoint +1.5242 Day_Night
N
34601
Rsq
0.0175
Adj Rsq
0.0174
RMSE
8.5443
Residual
Predicted Value
60
40
20
0
-20
-40
-60
-80
74
75
76
77
78
79
80
81

Storm 2 Minus Outliers Initial Model

The SAS System 12:33 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	37196
Number of Observations Used	34601
Number of Observations with Missing Values	2595

Analysis of Variance

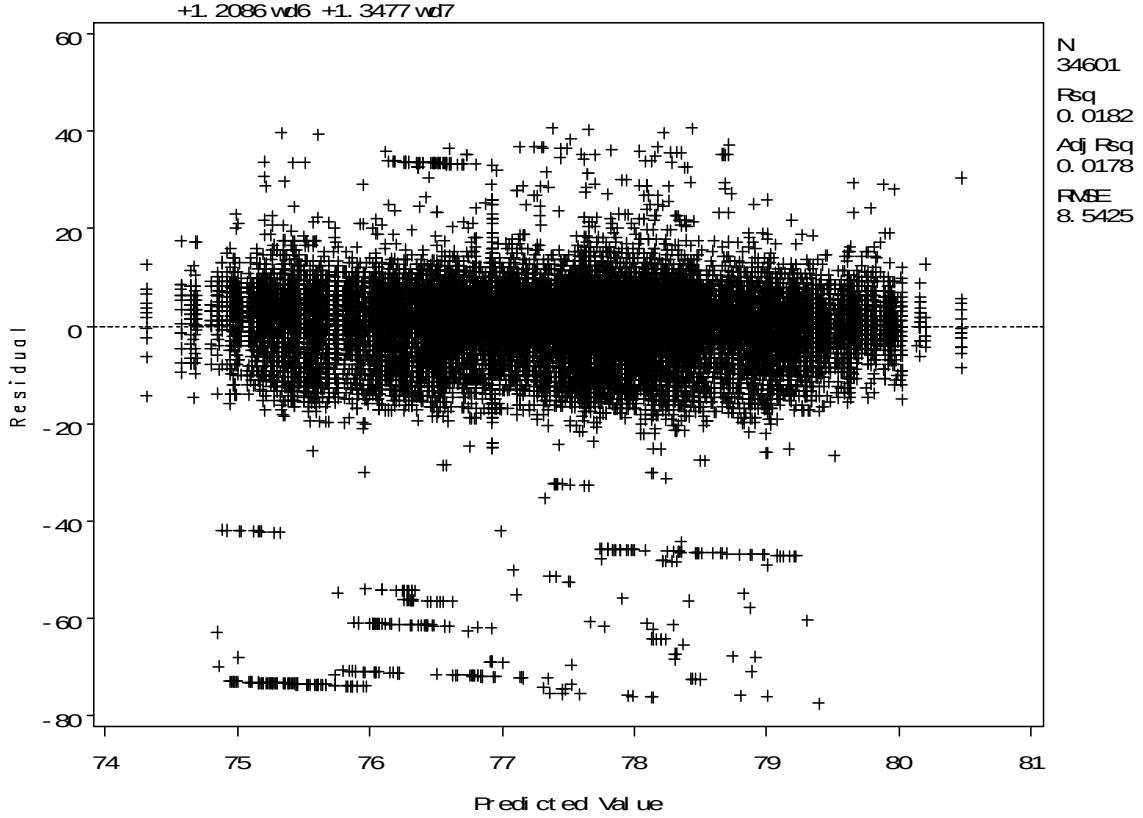
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	16	46889	2930.58025	40.16	<.0001
Error	34584	2523742	72.97428		
Corrected Total	34600	2570632			

Root MSE	8.54250	R-Square	0.0182
Dependent Mean	77.49623	Adj R-Sq	0.0178
Coeff Var	11.02312		

Parameter Estimates

Parameter Variable	Standard Label	DF	Estimate	Error	t Value	Pr > |t|
Intercept	Intercept	1	50.28397	1.69332	29.70	<.0001
SfStatus	SfStatus	1	1.46749	0.26104	5.62	<.0001
SfTemp	SfTemp	1	-0.02398	0.00858	-2.79	0.0052
SubTemp	SubTemp	1	0.36733	0.03064	11.99	<.0001
AvgWindSpeed	AvgWindSpeed	1	0.01002	0.02161	0.46	0.6429
GustWindSpeed	GustWindSpeed	1	-0.03562	0.01636	-2.18	0.0295
AirTemp	AirTemp	1	0.05155	0.01800	2.86	0.0042
RH	RH	1	0.01322	0.00446	2.96	0.0031
Dewpoint	Dewpoint	1	-0.01906	0.00673	-2.83	0.0046
Day_Night	Day_Night	1	1.51037	0.14604	10.34	<.0001
wd1		1	0.92166	0.68290	1.35	0.1771
wd2		1	1.08485	0.46068	2.35	0.0185
wd3		1	1.57588	0.45635	3.45	0.0006
wd4		1	1.56617	0.49998	3.13	0.0017
wd5		1	1.66759	0.46355	3.60	0.0003
wd6		1	1.20862	0.41537	2.91	0.0036
wd7		1	1.34766	0.41624	3.24	0.0012

AvgSpeed85 = 50.284 +1.4675 SfStatus -0.024 SfTemp +0.3673 SubTemp +0.01 AvgWndSpeed
-0.0356 GustWndSpeed +0.0516 AirTemp +0.0132 RH -0.0191 Dewpoint
+1.5104 Day_Night +0.9217 wd1 +1.0849 wd2 +1.5759 wd3 +1.5662 wd4 +1.6676 wd5
+1.2086 wd6 +1.3477 wd7



Storm 2 Minus Outliers Final Model

The SAS System 13:36 Thursday, May 28, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	37196
Number of Observations Used	34601
Number of Observations with Missing Values	2595

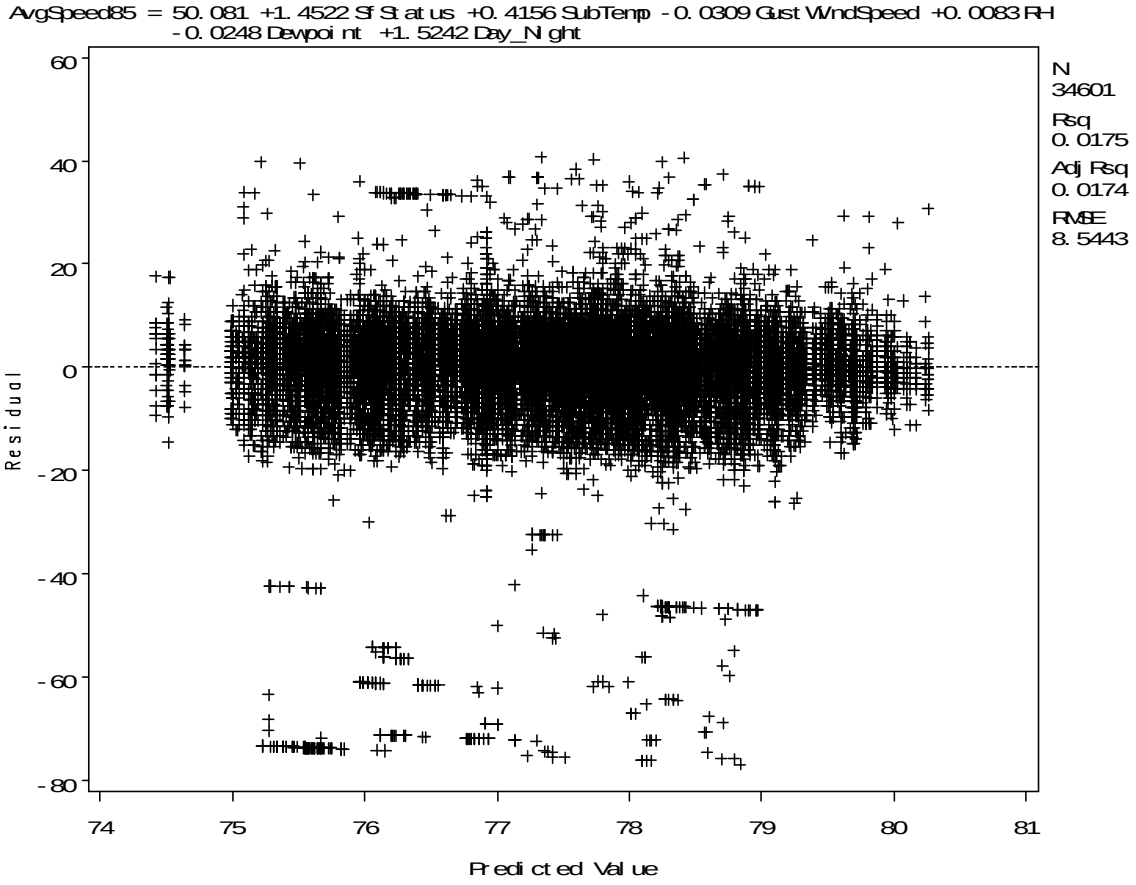
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	45092	7515.39138	102.94	<.0001
Error	34594	2525539	73.00513		
Corrected Total	34600	2570632			

Root MSE	8.54430	R-Square	0.0175
Dependent Mean	77.49623	Adj R-Sq	0.0174
Coeff Var	11.02544		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	50.08072	1.56377	32.03	<.0001	0
SfStatus	SfStatus	1	1.45216	0.25745	5.64	<.0001	1.45362
SubTemp	SubTemp	1	0.41564	0.02280	18.23	<.0001	1.64751
GustWindSpeed	GustWindSpeed	1	-0.03085	0.00548	-5.63	<.0001	1.55947
RH	RH	1	0.00831	0.00285	2.91	0.0036	2.59081
Dewpoint	Dewpoint	1	-0.02484	0.00497	-5.00	<.0001	2.54831
Day_Night	Day_Night	1	1.52422	0.10558	14.44	<.0001	1.31081


AvgSpeed85 = 50.081 +1.4522 SfStatus +0.4156 SubTemp -0.0309 GustWndSpeed +0.0083 RH
-0.0248 Dewpoint +1.5242 Day_Night
N
34601
Rsq
0.0175
Adj Rsq
0.0174
RMSE
8.5443
Residual
Predicted Value
60
40
20
0
-20
-40
-60
-80
74
75
76
77
78
79
80
81

Storm 3 Initial Model

The SAS System 12:42 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	65535
Number of Observations Used	29921
Number of Observations with Missing Values	35614

Analysis of Variance

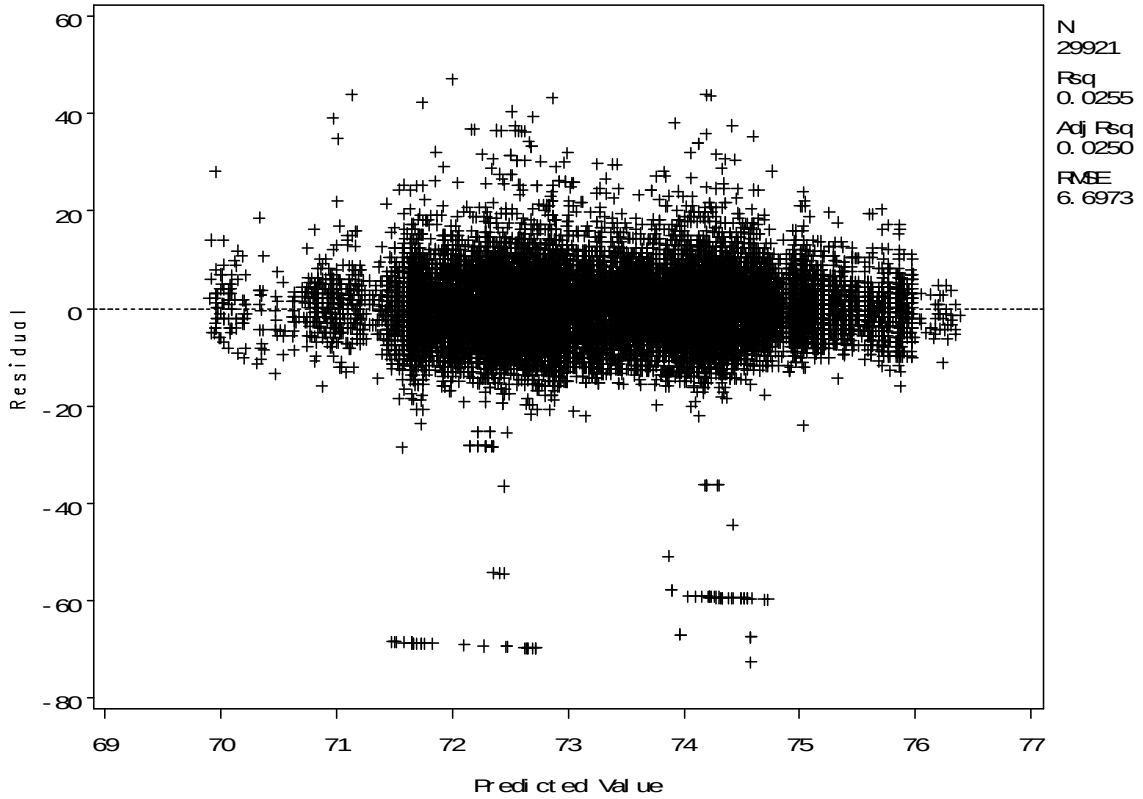
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	16	35069	2191.80840	48.86	<.0001
Error	29904	1341328	44.85447		
Corrected Total	29920	1376397			

Root MSE	6.69735	R-Square	0.0255
Dependent Mean	73.34778	Adj R-Sq	0.0250
Coeff Var	9.13095		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	67.52146	2.68425	25.15	<.0001	0
Day_Night	Day_Night	1	0.97200	0.12607	7.71	<.0001	2.64999
SfStatus	SfStatus	1	-1.28685	0.93551	-1.38	0.1690	1.05173
SfTemp	SfTemp	1	0.08378	0.00604	13.87	<.0001	4.20610
SubTemp	SubTemp	1	0.18278	0.04056	4.51	<.0001	2.80700
AirTemp	AirTemp	1	-0.09000	0.00920	-9.78	<.0001	4.22388
RH	RH	1	0.06087	0.00416	14.63	<.0001	3.19598
Dewpoint	Dewpoint	1	-0.12059	0.00820	-14.71	<.0001	3.66237
Vis1	Vis1	1	-0.00006193	0.00001572	-3.94	<.0001	1.75815
AvgWindSpeed	AvgWindSpeed	1	-0.03335	0.02495	-1.34	0.1814	10.32189
GustWindSpeed	GustWindSpeed	1	-0.01506	0.02028	-0.74	0.4578	10.83732
wd1		1	0.02407	3.47399	0.01	0.9945	1.07610
wd2		1	1.64375	2.54413	0.65	0.5182	1.15411
wd4		1	-0.39028	2.54221	-0.15	0.8780	1.15237
wd5		1	2.40668	1.91404	1.26	0.2086	1.30612
wd6		1	-0.80202	0.91103	-0.88	0.3787	138.37438
wd7		1	-0.73025	0.91008	-0.80	0.4223	138.05322

AvgSpeed85 = 67.521 +0.972 Day_Night -1.2869 SfStatus +0.0838 SfTemp +0.1828 SubTemp
-0.09 AirTemp +0.0609 RH -0.1206 Dewpoint -0.0001 Vis1 -0.0333 AvgWndSpeed
-0.0151 GustWndSpeed +0.0241 wd1 +1.6437 wd2 -0.3903 wd4 +2.4067 wd5
-0.802 wd6 -0.7303 wd7



Storm 3 Final Model

The SAS System 12:42 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	65535
Number of Observations Used	29921
Number of Observations with Missing Values	35614

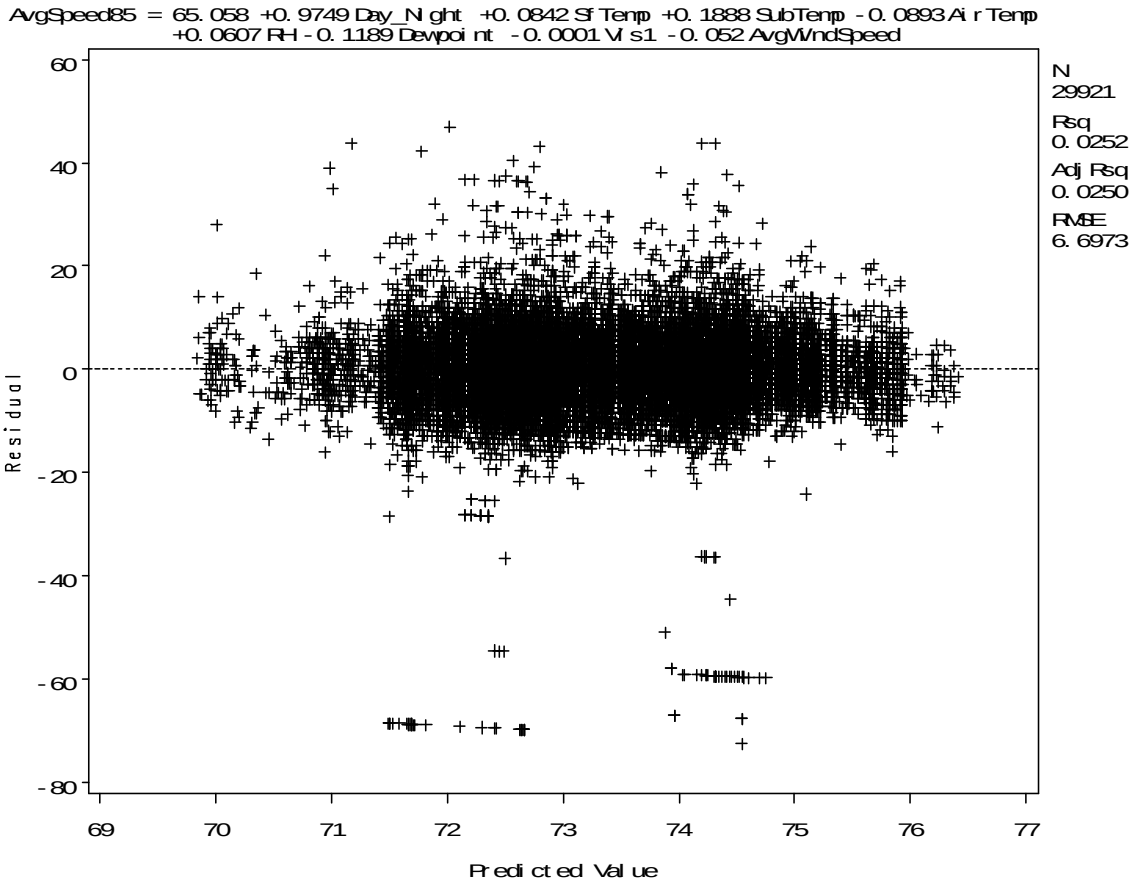
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	34716	4339.49553	96.75	<.0001
Error	29912	1341681	44.85427		
Corrected Total	29920	1376397			

Root MSE	6.69733	R-Square	0.0252
Dependent Mean	73.34778	Adj R-Sq	0.0250
Coeff Var	9.13093		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	65.05848	2.29925	28.30	<.0001	0
Day_Night	Day_Night	1	0.97487	0.12471	7.82	<.0001	2.59319
SfTemp	SfTemp	1	0.08418	0.00597	14.11	<.0001	4.10372
SubTemp	SubTemp	1	0.18882	0.04032	4.68	<.0001	2.77344
AirTemp	AirTemp	1	-0.08932	0.00889	-10.04	<.0001	3.94888
RH	RH	1	0.06066	0.00412	14.71	<.0001	3.14243
Dewpoint	Dewpoint	1	-0.11886	0.00813	-14.63	<.0001	3.59667
Vis1	Vis1	1	-0.00006154	0.00001552	-3.97	<.0001	1.71415
AvgWindSpeed	AvgWindSpeed	1	-0.05198	0.01007	-5.16	<.0001	1.67967


AvgSpeed85 = 65.058 +0.9749 Day_Night +0.0842 Sf Temp +0.1888 SubTemp -0.0893 Air Temp
+0.0607 RH -0.1189 Dewpoint -0.0001 Vis1 -0.052 AvgWindSpeed
N
29921
Rsq
0.0252
Adj Rsq
0.0250
RMSE
6.6973
Residual
Predicted Value
60
40
20
0
-20
-40
-60
-80
69
70
71
72
73
74
75
76
77

Storm 3 Minus Outliers Initial Model

The SAS System 12:49 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	65535
Number of Observations Used	35673
Number of Observations with Missing Values	29862

Analysis of Variance

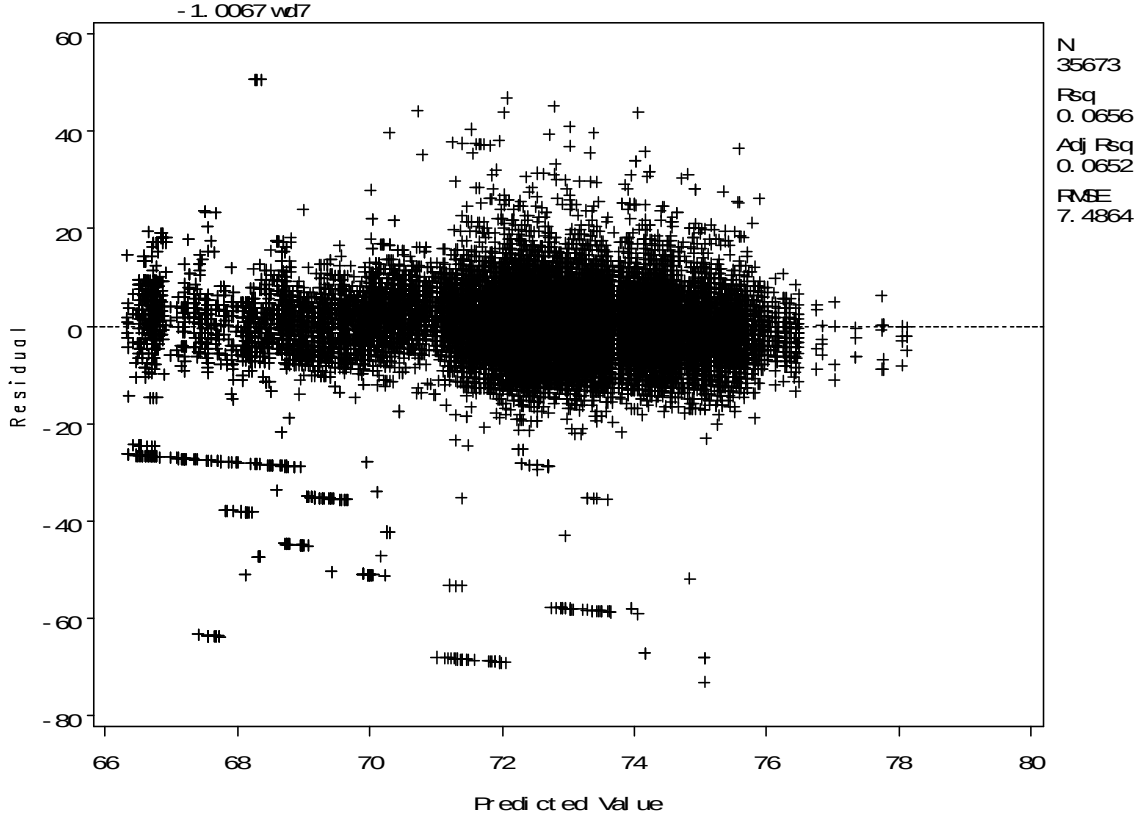
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	16	140278	8767.37216	156.43	<.0001
Error	35656	1998370	56.04581		
Corrected Total	35672	2138647			

Root MSE	7.48638	R-Square	0.0656
Dependent Mean	72.58997	Adj R-Sq	0.0652
Coeff Var	10.31324		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	40.55535	2.56900	15.79	<.0001
Day_Night	Day_Night	1	0.64387	0.12912	4.99	<.0001
SfStatus	SfStatus	1	-2.88202	1.03766	-2.78	0.0055
SfTemp	SfTemp	1	0.07723	0.00644	11.98	<.0001
SubTemp	SubTemp	1	0.62936	0.03958	15.90	<.0001
AirTemp	AirTemp	1	-0.06269	0.00934	-6.71	<.0001
RH	RH	1	0.03865	0.00417	9.26	<.0001
Dewpoint	Dewpoint	1	-0.06963	0.00733	-9.50	<.0001
Vis1	Vis1	1	0.00021165	0.00000527	40.15	<.0001
AvgWindSpeed	AvgWindSpeed	1	-0.00397	0.02547	-0.16	0.8762
GustWindSpeed	GustWindSpeed	1	-0.05594	0.02079	-2.69	0.0071
wd1		1	-0.87140	2.79531	-0.31	0.7552
wd2		1	0.39615	2.07684	0.19	0.8487
wd4		1	-1.03998	2.07511	-0.50	0.6163
wd5		1	1.36302	1.59951	0.85	0.3941
wd6		1	-1.02129	0.89469	-1.14	0.2537
wd7		1	-1.00673	0.89337	-1.13	0.2598

AvgSpeed85 = 40.555 +0.6439 Day_Night -2.882 SfStatus +0.0772 SfTemp +0.6294 SubTemp
-0.0627 AirTemp +0.0387 RH -0.0696 Dewpoint +0.0002 Vis1 -0.004 AvgWndSpeed
-0.0559 GustWndSpeed -0.8714 wd1 +0.3961 wd2 -1.04 wd4 +1.363 wd5 -1.0213 wd6
-1.0067 wd7



Storm 3 Minus Outliers Final Model

The SAS System 12:49 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	65535
Number of Observations Used	35673
Number of Observations with Missing Values	29862

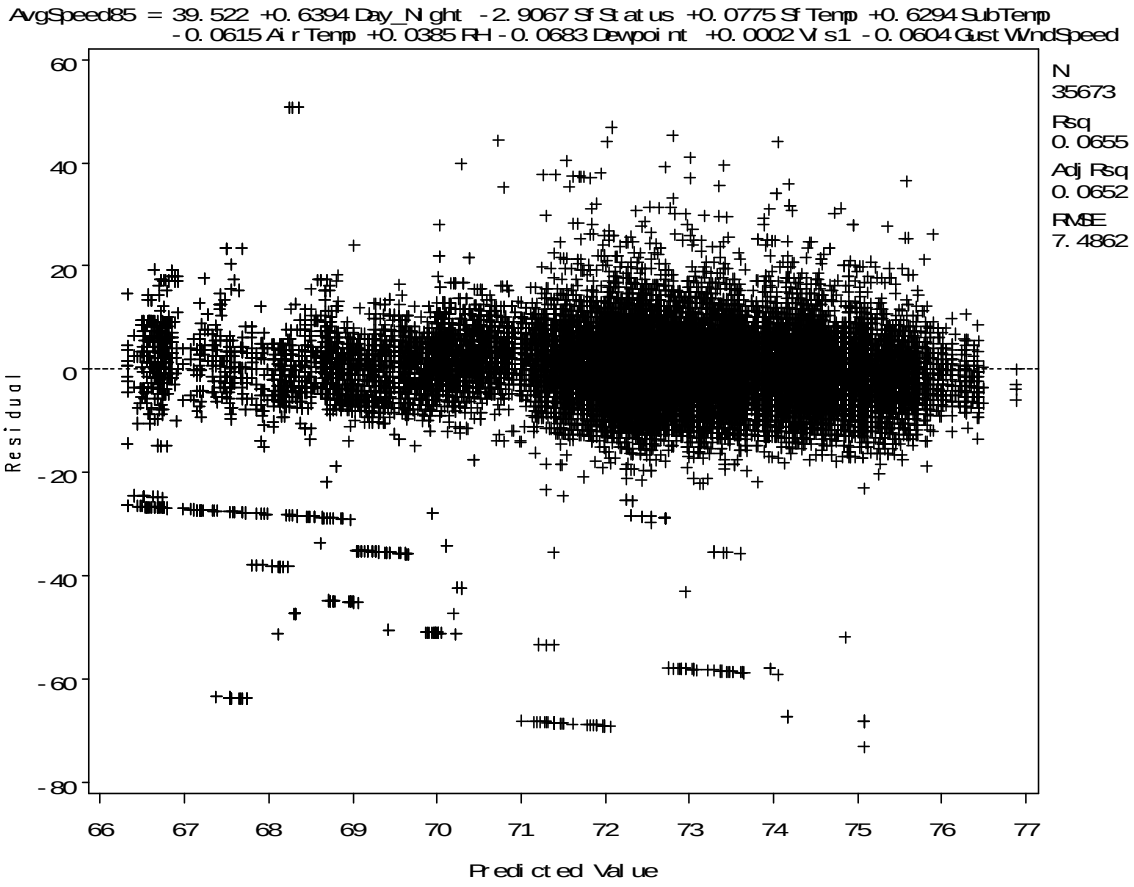
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	139992	15555	277.55	<.0001
Error	35663	1998656	56.04284		
Corrected Total	35672	2138647			

Root MSE	7.48618	R-Square	0.0655
Dependent Mean	72.58997	Adj R-Sq	0.0652
Coeff Var	10.31296		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	39.52174	2.36684	16.70	<.0001
Day_Night	Day_Night	1	0.63937	0.12708	5.03	<.0001
SfStatus	SfStatus	1	-2.90668	1.03114	-2.82	0.0048
SfTemp	SfTemp	1	0.07746	0.00634	12.22	<.0001
SubTemp	SubTemp	1	0.62941	0.03927	16.03	<.0001
AirTemp	AirTemp	1	-0.06152	0.00917	-6.71	<.0001
RH	RH	1	0.03847	0.00413	9.32	<.0001
Dewpoint	Dewpoint	1	-0.06832	0.00723	-9.45	<.0001
Vis1	Vis1	1	0.00021145	0.00000526	40.18	<.0001
GustWindSpeed	GustWindSpeed	1	-0.06041	0.00812	-7.44	<.0001


AvgSpeed85 = 39.522 +0.6394 Day_Night -2.9067 SfStatus +0.0775 SfTemp +0.6294 SubTemp
-0.0615 AirTemp +0.0385 RH -0.0683 Dewpoint +0.0002 Vis1 -0.0604 GustWindSpeed
N
35673
Rsq
0.0655
Adj Rsq
0.0652
RMSE
7.4862
Residual
Predicted Value
60
40
20
0
-20
-40
-60
-80
66
67
68
69
70
71
72
73
74
75
76
77

Storm 4 Initial Model

The SAS System 13:05 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	45821
Number of Observations Used	39244
Number of Observations with Missing Values	6577

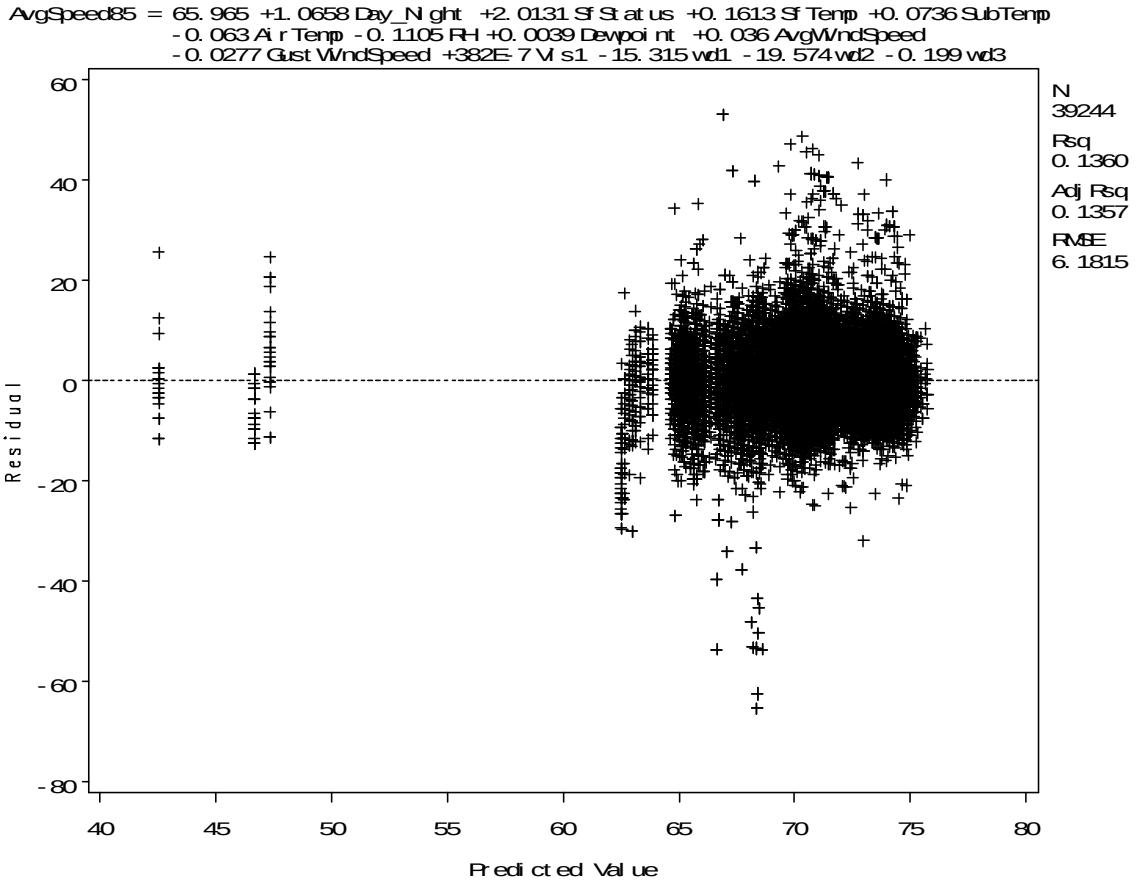
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	13	235917	18147	474.92	<.0001
Error	39230	1499026	38.21121		
Corrected Total	39243	1734943			

Root MSE	6.18152	R-Square	0.1360
Dependent Mean	70.90055	Adj R-Sq	0.1357
Coeff Var	8.71858		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	65.96480	0.70268	93.88	<.0001	0
Day_Night	Day_Night	1	1.06579	0.09812	10.86	<.0001	2.46986
SfStatus	SfStatus	1	2.01306	0.33215	6.06	<.0001	1.38861
SfTemp	SfTemp	1	0.16130	0.01020	15.82	<.0001	13.28920
SubTemp	SubTemp	1	0.07363	0.01718	4.29	<.0001	2.90438
AirTemp	AirTemp	1	-0.06301	0.01051	-5.99	<.0001	11.80364
RH	RH	1	-0.11047	0.00422	-26.16	<.0001	2.94363
Dewpoint	Dewpoint	1	0.00393	0.00225	1.75	0.0807	1.24417
AvgWindSpeed	AvgWindSpeed	1	0.03599	0.01315	2.74	0.0062	9.58798
GustWindSpeed	GustWindSpeed	1	-0.02767	0.01014	-2.73	0.0064	10.95643
Vis1	Vis1	1	0.00003817	0.00000467	8.17	<.0001	1.01569
wd1		1	-15.31515	0.98006	-15.63	<.0001	1.15495
wd2		1	-19.57423	1.42689	-13.72	<.0001	1.06511
wd3		1	-0.19902	0.07915	-2.51	0.0119	1.41578


AvgSpeed85 = 65.965 +1.0658 Day_Night +2.0131 SfStatus +0.1613 SfTemp +0.0736 SubTemp
-0.063 AirTemp -0.1105 RH +0.0039 Dewpoint +0.036 AvgWindSpeed
-0.0277 GustWindSpeed +382E-7 Vis1 -15.315 wd1 -19.574 wd2 -0.199 wd3
N
39244
Rsq
0.1360
Adj Rsq
0.1357
RMSE
6.1815
Residual
Predicted Value
60
40
20
0
-20
-40
-60
-80
40
45
50
55
60
65
70
75
80

Storm 4 Final Model

The SAS System 13:05 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	45821
Number of Observations Used	39735
Number of Observations with Missing Values	6086

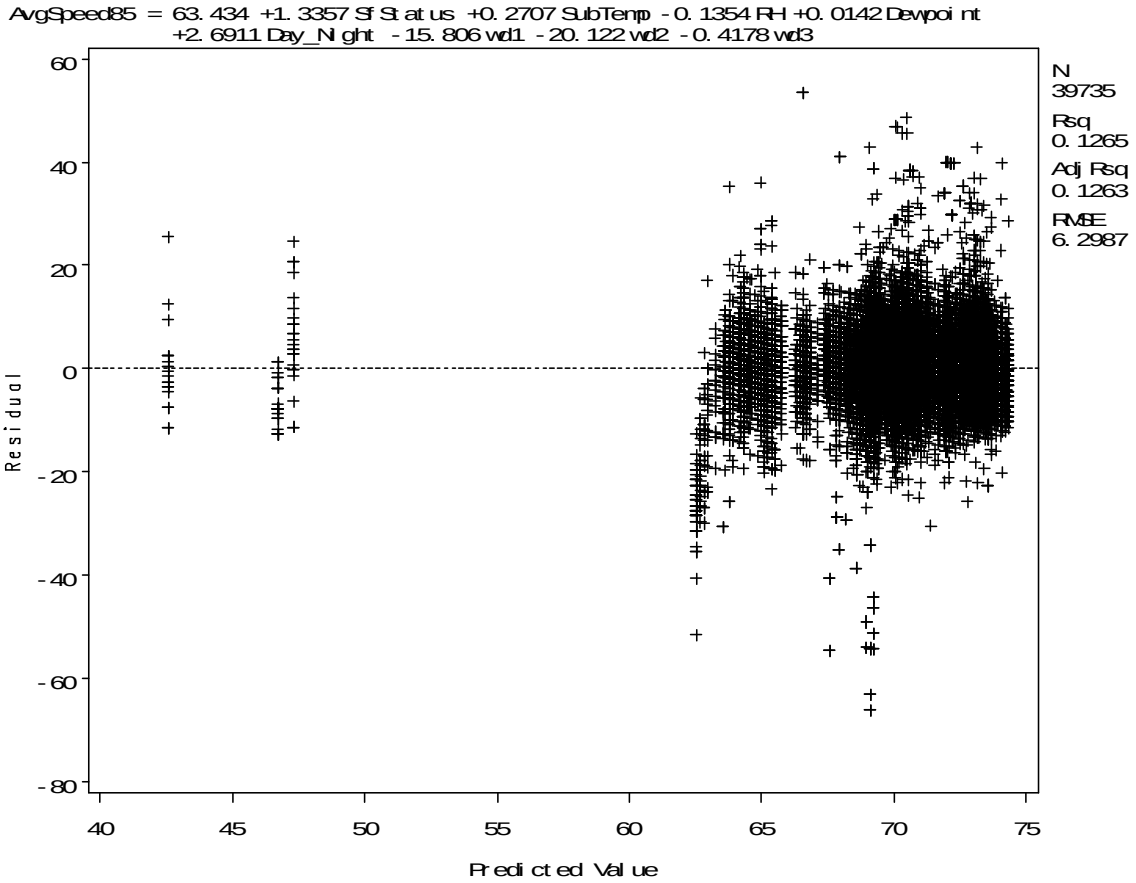
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	228226	28528	719.08	<.0001
Error	39726	1576066	39.67342		
Corrected Total	39734	1804292			

Root MSE	6.29868	R-Square	0.1265
Dependent Mean	70.86090	Adj R-Sq	0.1263
Coeff Var	8.88880		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	63.43391	0.52638	120.51	<.0001	0
SfStatus	SfStatus	1	1.33573	0.22407	5.96	<.0001	1.20718
SubTemp	SubTemp	1	0.27070	0.01225	22.09	<.0001	1.43287
RH	RH	1	-0.13542	0.00305	-44.37	<.0001	1.57316
Dewpoint	Dewpoint	1	0.01423	0.00223	6.37	<.0001	1.18705
Day_Night	Day_Night	1	2.69106	0.06736	39.95	<.0001	1.13496
wd1		1	-15.80572	0.95352	-16.58	<.0001	1.05297
wd2		1	-20.12222	1.42505	-14.12	<.0001	1.02322
wd3		1	-0.41783	0.07624	-5.48	<.0001	1.2943


AvgSpeed85 = 63.434 +1.3357 SfStatus +0.2707 SubTemp -0.1354 RH +0.0142 Dewpoint
+2.6911 Day_Night -15.806 wd1 -20.122 wd2 -0.4178 wd3
N
39735
Rsq
0.1265
Adj Rsq
0.1263
RMSE
6.2987
Residual
Predicted Value
60
40
20
0
-20
-40
-60
-80
40
45
50
55
60
65
70
75

Storm 4 Minus Outliers Initial Model

The SAS System 13:16 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	45821
Number of Observations Used	39244
Number of Observations with Missing Values	6577

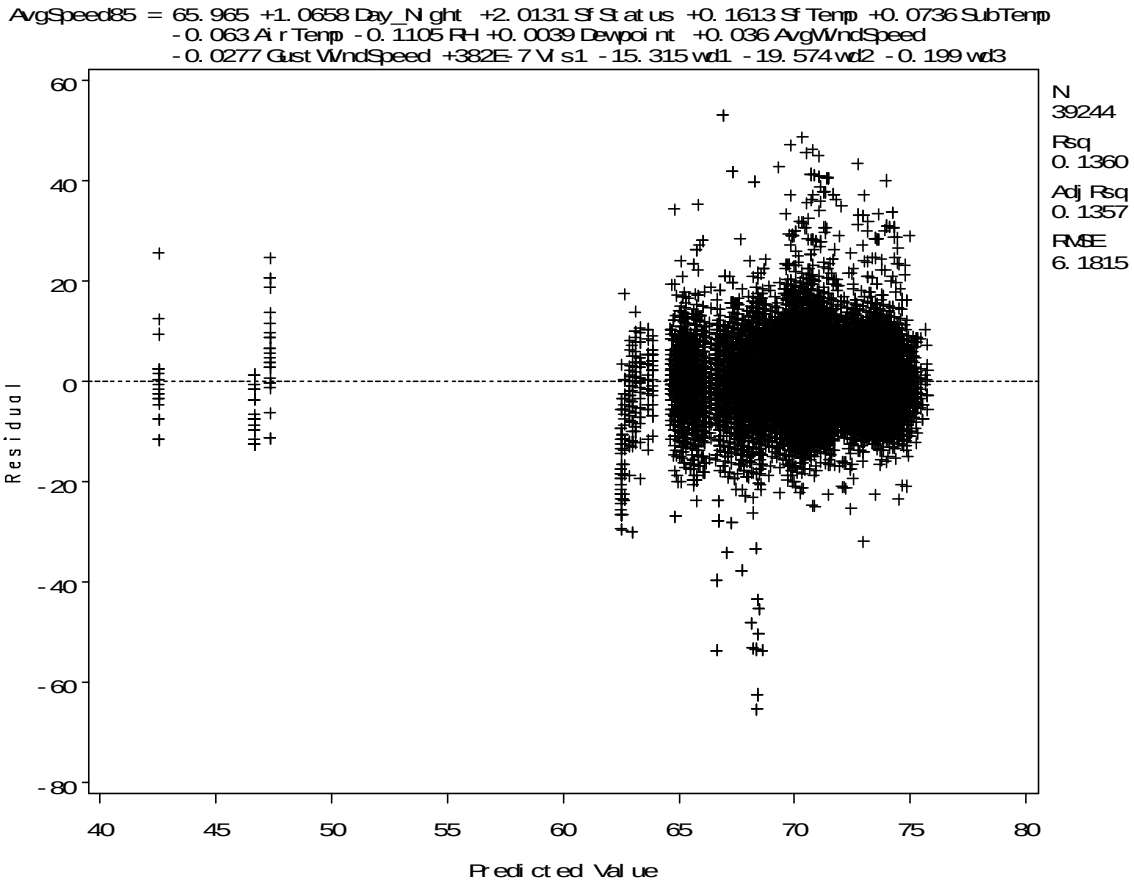
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	13	235917	18147	474.92	<.0001
Error	39230	1499026	38.21121		
Corrected Total	39243	1734943			

Root MSE	6.18152	R-Square	0.1360
Dependent Mean	70.90055	Adj R-Sq	0.1357
Coeff Var	8.71858		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	65.96480	0.70268	93.88	<.0001	0
Day_Night	Day_Night	1	1.06579	0.09812	10.86	<.0001	2.46986
SfStatus	SfStatus	1	2.01306	0.33215	6.06	<.0001	1.38861
SfTemp	SfTemp	1	0.16130	0.01020	15.82	<.0001	13.28920
SubTemp	SubTemp	1	0.07363	0.01718	4.29	<.0001	2.90438
AirTemp	AirTemp	1	-0.06301	0.01051	-5.99	<.0001	11.80364
RH	RH	1	-0.11047	0.00422	-26.16	<.0001	2.94363
Dewpoint	Dewpoint	1	0.00393	0.00225	1.75	0.0807	1.24417
AvgWindSpeed	AvgWindSpeed	1	0.03599	0.01315	2.74	0.0062	9.58798
GustWindSpeed	GustWindSpeed	1	-0.02767	0.01014	-2.73	0.0064	10.95643
Vis1	Vis1	1	0.00003817	0.00000467	8.17	<.0001	1.01569
wd1		1	-15.31515	0.98006	-15.63	<.0001	1.15495
wd2		1	-19.57423	1.42689	-13.72	<.0001	1.06511
wd3		1	-0.19902	0.07915	-2.51	0.0119	1.41578


AvgSpeed85 = 65.965 +1.0658 Day_Night +2.0131 SfStatus +0.1613 SfTemp +0.0736 SubTemp
-0.063 AirTemp -0.1105 RH +0.0039 Dewpoint +0.036 AvgWndSpeed
-0.0277 GustWndSpeed +382E-7 Vis1 -15.315 wd1 -19.574 wd2 -0.199 wd3
N
39244
Rsq
0.1360
Adj Rsq
0.1357
RMSE
6.1815
Residual
Predicted Value
60
40
20
0
-20
-40
-60
-80
40
45
50
55
60
65
70
75
80

Storm 4 Minus Outliers Final Model

The SAS System 13:16 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	45821
Number of Observations Used	39656
Number of Observations with Missing Values	6165

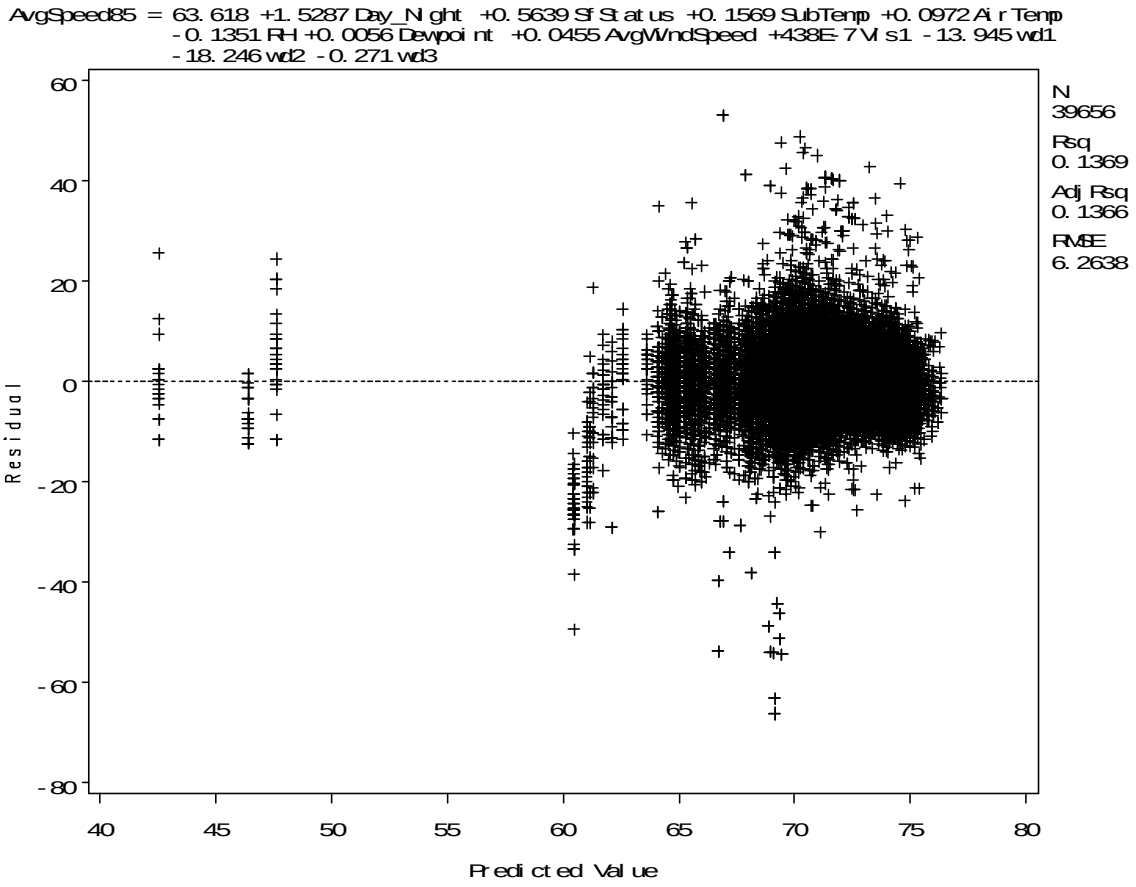
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	246676	22425	571.55	<.0001
Error	39644	1555449	39.23542		
Corrected Total	39655	1802125			

Root MSE	6.26382	R-Square	0.1369
Dependent Mean	70.86000	Adj R-Sq	0.1366
Coeff Var	8.83971		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	63.61752	0.66636	95.47	<.0001	0
Day_Night	Day_Night	1	1.52865	0.09016	16.95	<.0001	2.05238
SfStatus	SfStatus	1	0.56393	0.24617	2.29	0.0220	1.35706
SubTemp	SubTemp	1	0.15694	0.01658	9.47	<.0001	2.64625
AirTemp	AirTemp	1	0.09724	0.00504	19.29	<.0001	2.65761
RH	RH	1	-0.13511	0.00383	-35.28	<.0001	2.50492
Dewpoint	Dewpoint	1	0.00557	0.00227	2.45	0.0142	1.24110
AvgWindSpeed	AvgWindSpeed	1	0.04551	0.00655	6.95	<.0001	2.36074
Vis1	Vis1	1	0.00004384	0.00000473	9.28	<.0001	1.01556
wd1		1	-13.94466	0.97183	-14.35	<.0001	1.10600
wd2		1	-18.24618	1.43144	-12.75	<.0001	1.04394
wd3		1	-0.27102	0.07777	-3.48	0.0005	1.35902


AvgSpeed85 = 63.618 +1.5287 Day_Night +0.5639 SfStatus +0.1569 SubTemp +0.0972 Air Temp
-0.1351 RH +0.0056 Dewpoint +0.0455 AvgWindSpeed +438E-7 Vis1 -13.945 wd1
-18.246 wd2 -0.271 wd3
N
39656
Rsq
0.1369
Adj Rsq
0.1366
RMSE
6.2638
Residual
Predicted Value
60
40
20
0
-20
-40
-60
-80
40
45
50
55
60
65
70
75
80

Arlington Sensor Initial Model

The REG Procedure

Model: MODEL1

Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	4977
Number of Observations Used	1974
Number of Observations with Missing Values	3003

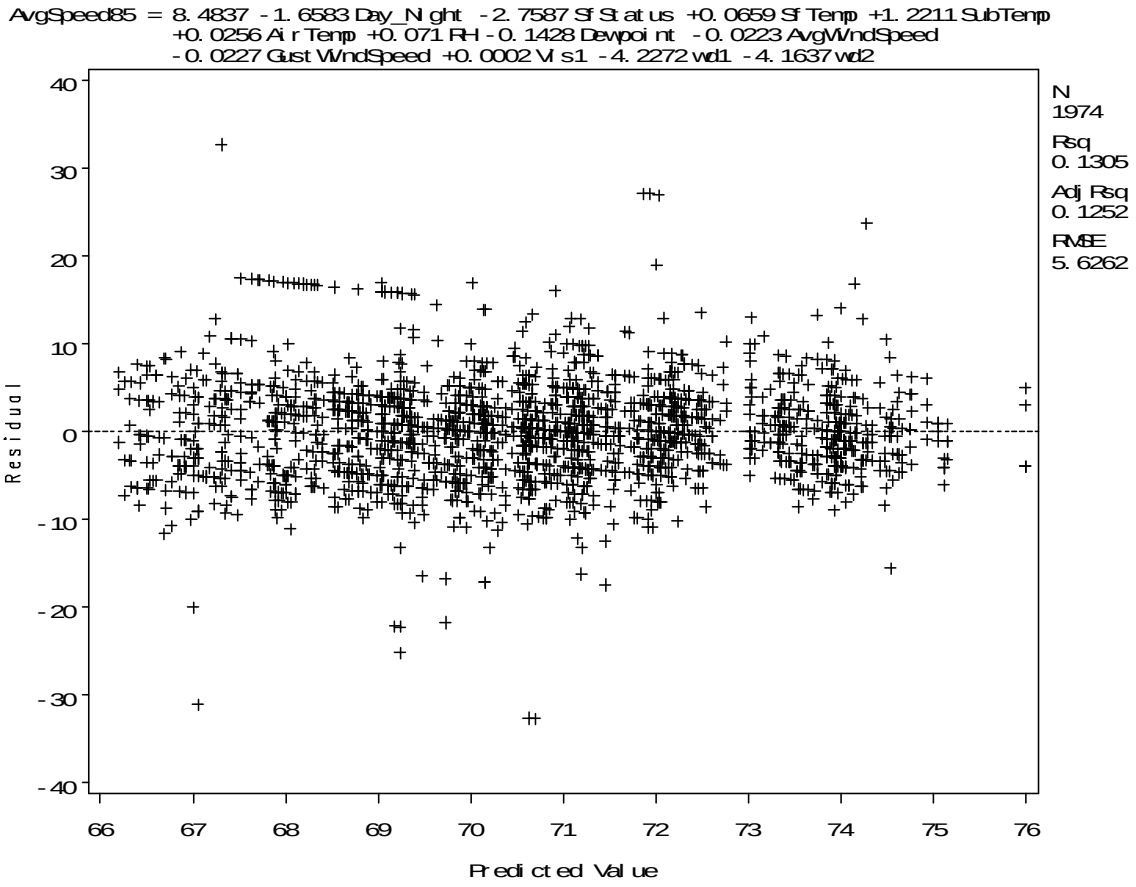
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	12	9318.17098	776.51425	24.53	<.0001
Error	1961	62073	31.65372		
Corrected Total	1973	71391			

Root MSE	5.62616	R-Square	0.1305
Dependent Mean	70.68338	Adj R-Sq	0.1252
Coeff Var	7.95967		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	8.48373	10.32017	0.82	0.4111	0
Day_Night	Day_Night	1	-1.65825	0.48466	-3.42	0.0006	3.64267
SfStatus	SfStatus	1	-2.75873	2.14081	-1.29	0.1977	1.15361
SfTemp	SfTemp	1	0.06592	0.03220	2.05	0.0408	11.22807
SubTemp	SubTemp	1	1.22107	0.13460	9.07	<.0001	2.59883
AirTemp	AirTemp	1	0.02561	0.12385	0.21	0.8362	58.15889
RH	RH	1	0.07101	0.11436	0.62	0.5347	55.79037
Dewpoint	Dewpoint	1	-0.14285	0.10883	-1.31	0.1895	15.17520
AvgWindSpeed	AvgWindSpeed	1	-0.02227	0.08373	-0.27	0.7903	6.97314
GustWindSpeed	GustWindSpeed	1	-0.02266	0.06900	-0.33	0.7426	8.01380
Vis1	Vis1	1	0.00015880	0.00005517	2.88	0.0040	1.54191
wd1		1	-4.22724	3.04246	-1.39	0.1649	139.62134
wd2		1	-4.16374	3.05478	-1.36	0.1730	140.53939


AvgSpeed85 = 8.4837 - 1.6583 Day_Night - 2.7587 SfStatus +0.0659 SfTemp +1.2211 SubTemp
+0.0256 Air Temp +0.071 RH - 0.1428 Dewpoint - 0.0223 AvgWndSpeed
- 0.0227 GustWndSpeed +0.0002 Vis1 - 4.2272 wd1 - 4.1637 wd2
N
1974
Rsq
0.1305
Adj Rsq
0.1252
RMSE
5.6262
Residual
Predicted Value
40
30
20
10
0
-10
-20
-30
-40
66
67
68
69
70
71
72
73
74
75
76

Arlington Sensor Final Model

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	4977
Number of Observations Used	1974
Number of Observations with Missing Values	3003

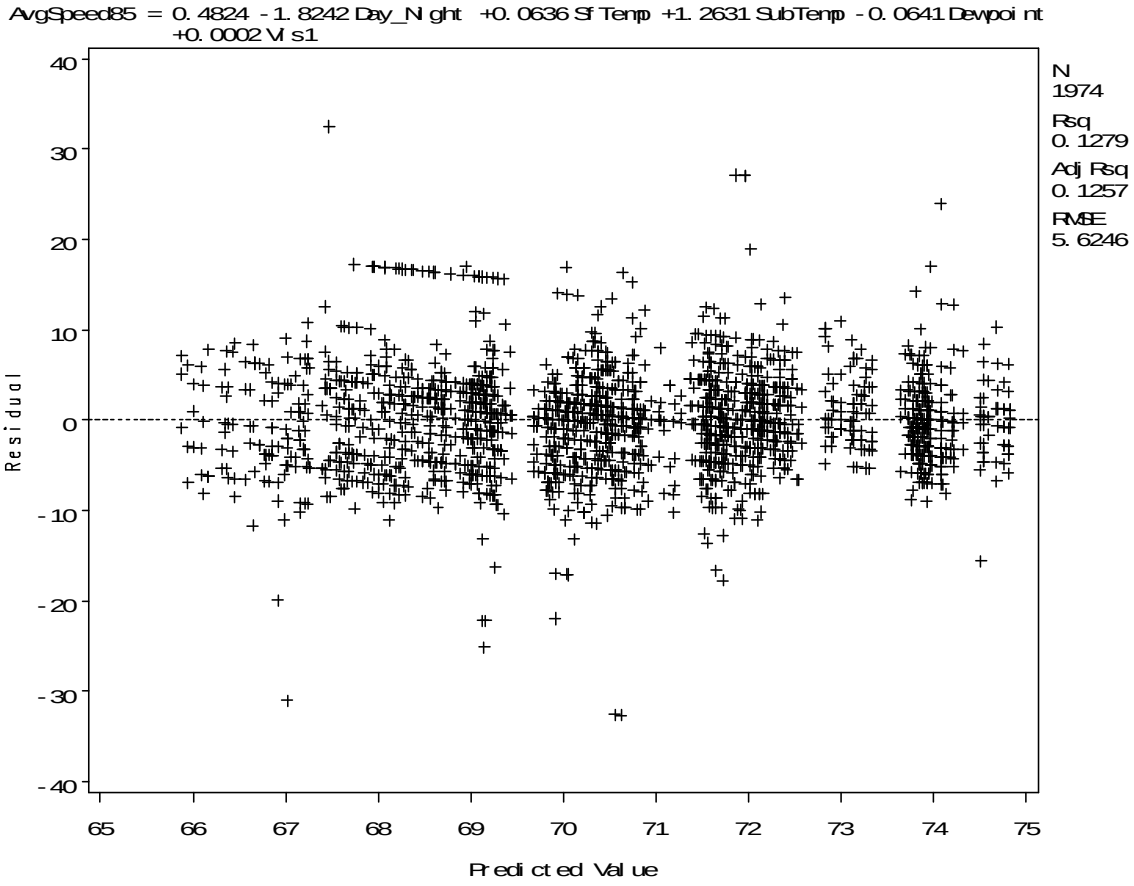
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	9130.97998	1826.19600	57.72	<.0001
Error	1968	62260	31.63625		
Corrected Total	1973	71391			

Root MSE	5.62461	R-Square	0.1279
Dependent Mean	70.68338	Adj R-Sq	0.1257
Coeff Var	7.95747		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	0.48236	6.35480	0.08	0.9395	0
Day_Night	Day_Night	1	-1.82424	0.44022	-4.14	<.0001	3.00695
SfTemp	SfTemp	1	0.06357	0.01456	4.37	<.0001	2.29763
SubTemp	SubTemp	1	1.26315	0.11933	10.59	<.0001	2.04382
Dewpoint	Dewpoint	1	-0.06411	0.03669	-1.75	0.0807	1.72558
Vis1	Vis1	1	0.00017446	0.00004945	3.53	0.0004	1.23941


AvgSpeed85 = 0.4824 - 1.8242 Day_Night +0.0636 SfTemp +1.2631 SubTemp - 0.0641 Dewpoint
+0.0002 Vis1
N
1974
Rsq
0.1279
Adj Rsq
0.1257
RMSE
5.6246
Residual
Predicted Value
40
30
20
10
0
-10
-20
-30
-40
65
66
67
68
69
70
71
72
73
74
75

Arlington Sensor Minus Outliers Initial Model

The SAS System 13:27 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	5760
Number of Observations Used	2292
Number of Observations with Missing Values	3468

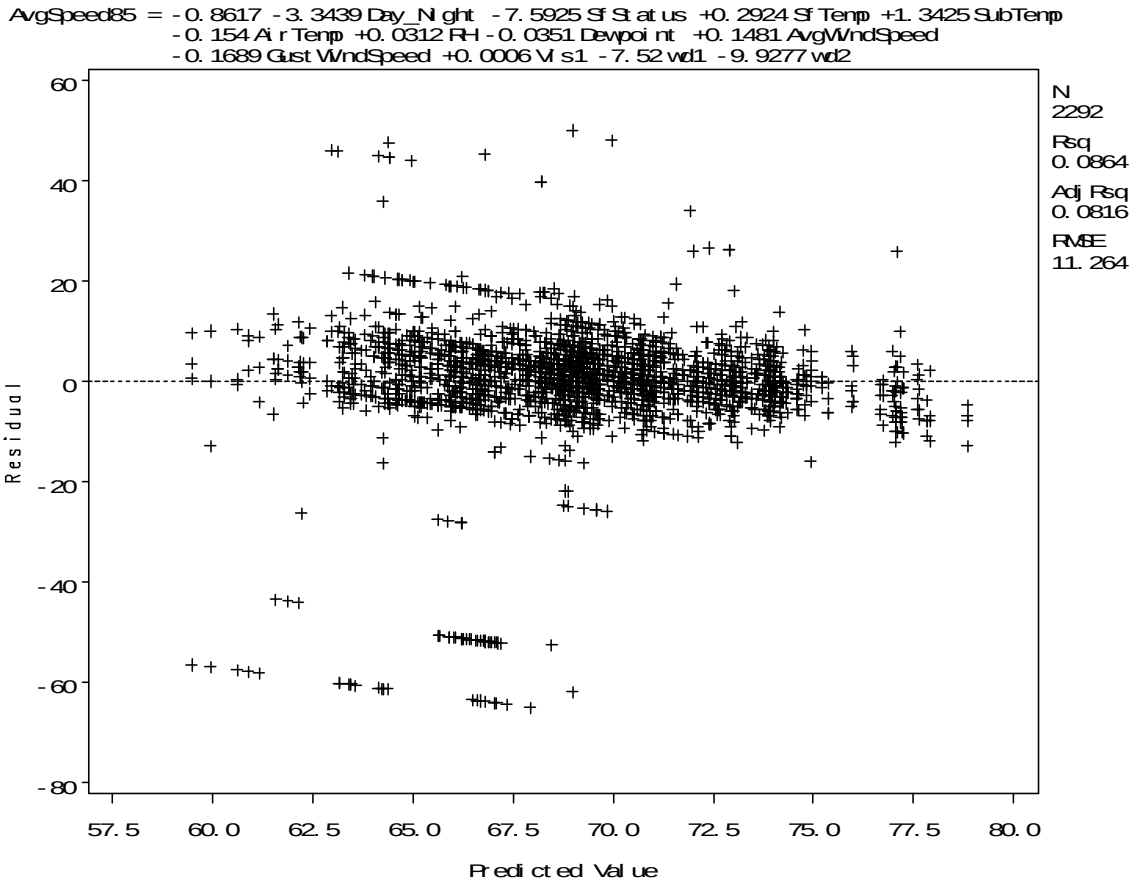
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	12	27338	2278.13415	17.95	<.0001
Error	2279	289173	126.88587		
Corrected Total	2291	316511			

Root MSE	11.26436	R-Square	0.0864
Dependent Mean	69.09904	Adj R-Sq	0.0816
Coeff Var	16.30176		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	-0.86167	19.56027	-0.04	0.9649	0
Day_Night	Day_Night	1	-3.34390	0.88932	-3.76	0.0002	3.56473
SfStatus	SfStatus	1	-7.59249	4.25527	-1.78	0.0745	1.13766
SfTemp	SfTemp	1	0.29243	0.05911	4.95	<.0001	11.50591
SubTemp	SubTemp	1	1.34250	0.25343	5.30	<.0001	2.64391
AirTemp	AirTemp	1	-0.15399	0.22976	-0.67	0.5028	59.46090
RH	RH	1	0.03124	0.21458	0.15	0.8842	56.59627
Dewpoint	Dewpoint	1	-0.03509	0.20516	-0.17	0.8642	14.96050
AvgWindSpeed	AvgWindSpeed	1	0.14811	0.15687	0.94	0.3452	6.54093
GustWindSpeed	GustWindSpeed	1	-0.16888	0.13007	-1.30	0.1943	7.53197
Vis1	Vis1	1	0.00061613	0.00010340	5.96	<.0001	1.55192
wd1		1	-7.52003	6.04164	-1.24	0.2134	159.30040
wd2		1	-9.92770	6.06244	-1.64	0.1016	160.18474


AvgSpeed85 = -0.8617 -3.3439 Day_Night -7.5925 SfStatus +0.2924 SfTemp +1.3425 SubTemp
-0.154 AirTemp +0.0312 RH -0.0351 Dewpoint +0.1481 AvgWindSpeed
-0.1689 GustWindSpeed +0.0006 Vis1 -7.52 wd1 -9.9277 wd2
N
2292
Rsq
0.0864
Adj Rsq
0.0816
RMSE
11.264
Residual
Predicted Value
60
40
20
0
-20
-40
-60
-80
57.5
60.0
62.5
65.0
67.5
70.0
72.5
75.0
77.5
80.0

Arlington Sensor Minus Outliers Final Model

The SAS System 13:27 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	5760
Number of Observations Used	2292
Number of Observations with Missing Values	3468

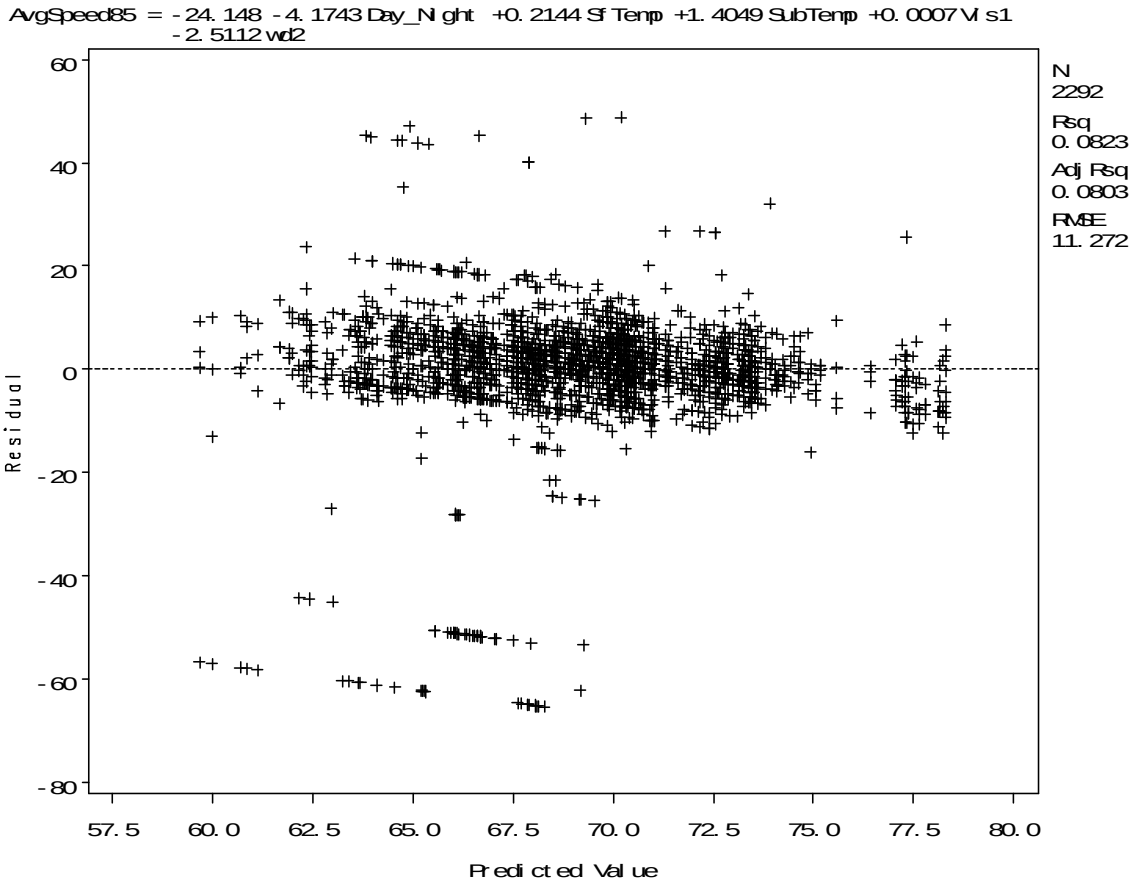
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	26047	5209.35620	41.00	<.0001
Error	2286	290464	127.06200		
Corrected Total	2291	316511			

Root MSE	11.27218	R-Square	0.0823
Dependent Mean	69.09904	Adj R-Sq	0.0803
Coeff Var	16.31307		

Parameter Estimates

Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	VIF	Variable
Intercept	Intercept	1	-24.14785	12.26046	-1.97	0.0490	0
Day_Night	Day_Night	1	-4.17434	0.82416	-5.06	<.0001	3.05728
SfTemp	SfTemp	1	0.21438	0.02740	7.83	<.0001	2.46816
SubTemp	SubTemp	1	1.40487	0.22103	6.36	<.0001	2.00834
Vis1	Vis1	1	0.00065381	0.00009193	7.11	<.0001	1.22503
wd2		1	-2.51123	0.61987	-4.05	<.0001	1.6723



Sensor 16 Initial Model

The SAS System 13:34 Monday, May 25, 2009

The REG Procedure
Model: MODEL1

Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	65535
Number of Observations Used	4688
Number of Observations with Missing Values	60847

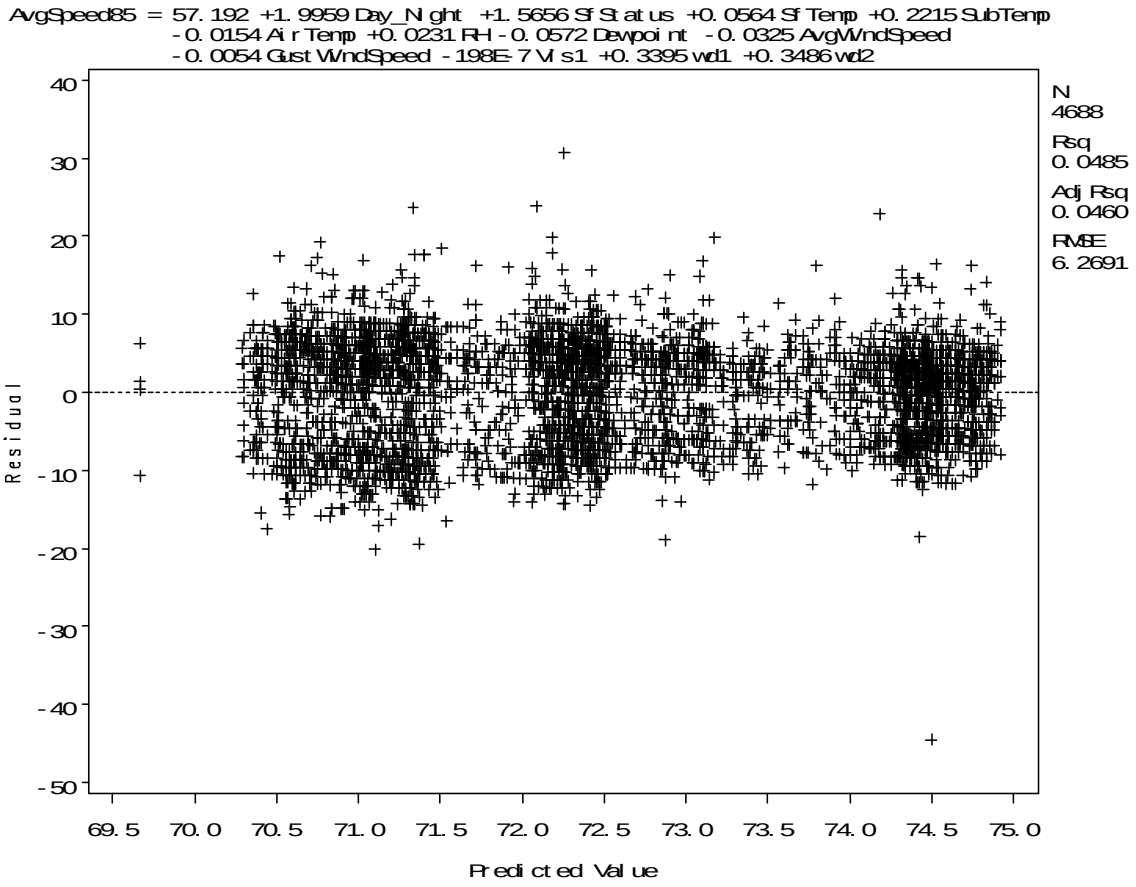
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	12	9360.01975	780.00165	19.85	<.0001
Error	4675	183736	39.30176		
Corrected Total	4687	193096			

Root MSE	6.26911	R-Square	0.0485
Dependent Mean	72.62585	Adj R-Sq	0.0460
Coeff Var	8.63207		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	57.19152	6.87780	8.32	<.0001	0
Day_Night	Day_Night	1	1.99586	0.32988	6.05	<.0001	3.24186
SfStatus	SfStatus	1	1.56561	2.27765	0.69	0.4919	1.05417
SfTemp	SfTemp	1	0.05640	0.01788	3.16	0.0016	6.43542
SubTemp	SubTemp	1	0.22155	0.10430	2.12	0.0337	3.31916
AirTemp	AirTemp	1	-0.01536	0.02923	-0.53	0.5993	7.56544
RH	RH	1	0.02310	0.00989	2.34	0.0196	3.31427
Dewpoint	Dewpoint	1	-0.05718	0.02127	-2.69	0.0072	4.47915
AvgWindSpeed	AvgWindSpeed	1	-0.03249	0.06072	-0.54	0.5926	11.05449
GustWindSpeed	GustWindSpeed	1	-0.00538	0.04905	-0.11	0.9127	11.53336
Vis1	Vis1	1	-0.00001982	0.00004572	-0.43	0.6647	2.63150
wd1		1	0.33947	2.25454	0.15	0.8803	151.57291
wd2		1	0.34855	2.25446	0.15	0.8771	151.55559


AvgSpeed85 = 57.192 +1.9959 Day_Night +1.5656 SfStatus +0.0564 SfTemp +0.2215 SubTemp
-0.0154 Air Temp +0.0231 RH -0.0572 Dewpoint -0.0325 AvgWndSpeed
-0.0054 Gust WndSpeed -198E-7 Vis1 +0.3395 wd1 +0.3486 wd2
N
4688
Rsq
0.0485
Adj Rsq
0.0460
RMSE
6.2691
Residual
Predicted Value
40
30
20
10
0
-10
-20
-30
-40
-50
69.5
70.0
70.5
71.0
71.5
72.0
72.5
73.0
73.5
74.0
74.5
75.0

Sensor 16 Final Model

The SAS System 13:34 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	65535
Number of Observations Used	4688
Number of Observations with Missing Values	60847

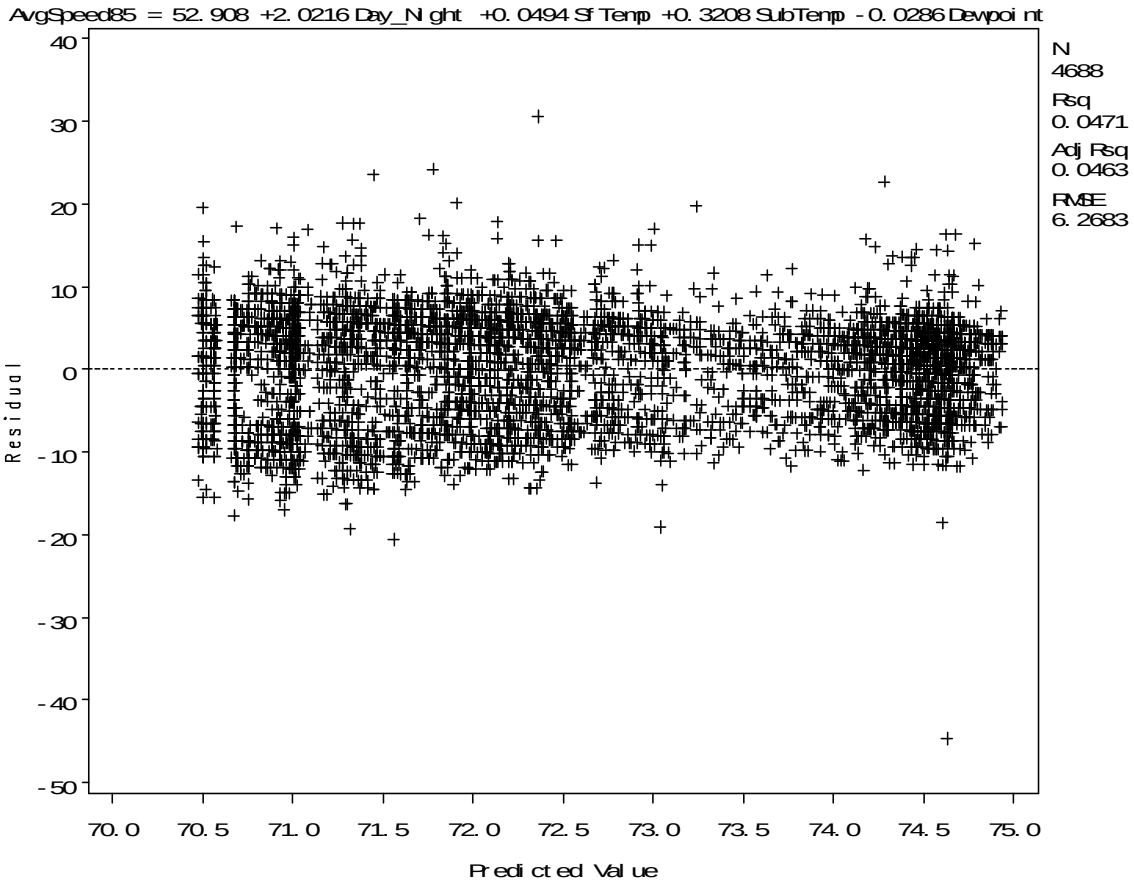
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	9093.43782	2273.35945	57.86	<.0001
Error	4683	184002	39.29155		
Corrected Total	4687	193096			

Root MSE	6.26830	R-Square	0.0471
Dependent Mean	72.62585	Adj R-Sq	0.0463
Coeff Var	8.63094		

Parameter Estimates

Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	VIF	Variable
Intercept	Intercept	1	52.90848	4.00986	13.19	<.0001	0
Day_Night	Day_Night	1	2.02160	0.29939	6.75	<.0001	2.67102
SfTemp	SfTemp	1	0.04935	0.01037	4.76	<.0001	2.16629
SubTemp	SubTemp	1	0.32080	0.08048	3.99	<.0001	1.97675
Dewpoint	Dewpoint	1	-0.02860	0.01250	-2.29	0.0221	1.5466


AvgSpeed85 = 52.908 +2.0216 Day_Night +0.0494 SfTemp +0.3208 SubTemp -0.0286 Dewpoint
N
4688
Rsq
0.0471
Adj Rsq
0.0463
RMSE
6.2683
Residual
40
30
20
10
0
-10
-20
-30
-40
-50
70.0
70.5
71.0
71.5
72.0
72.5
73.0
73.5
74.0
74.5
75.0
Predicted Value

Sensor 16 Minus Outliers Initial Model

The SAS System 13:41 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	65535
Number of Observations Used	4688
Number of Observations with Missing Values	60847

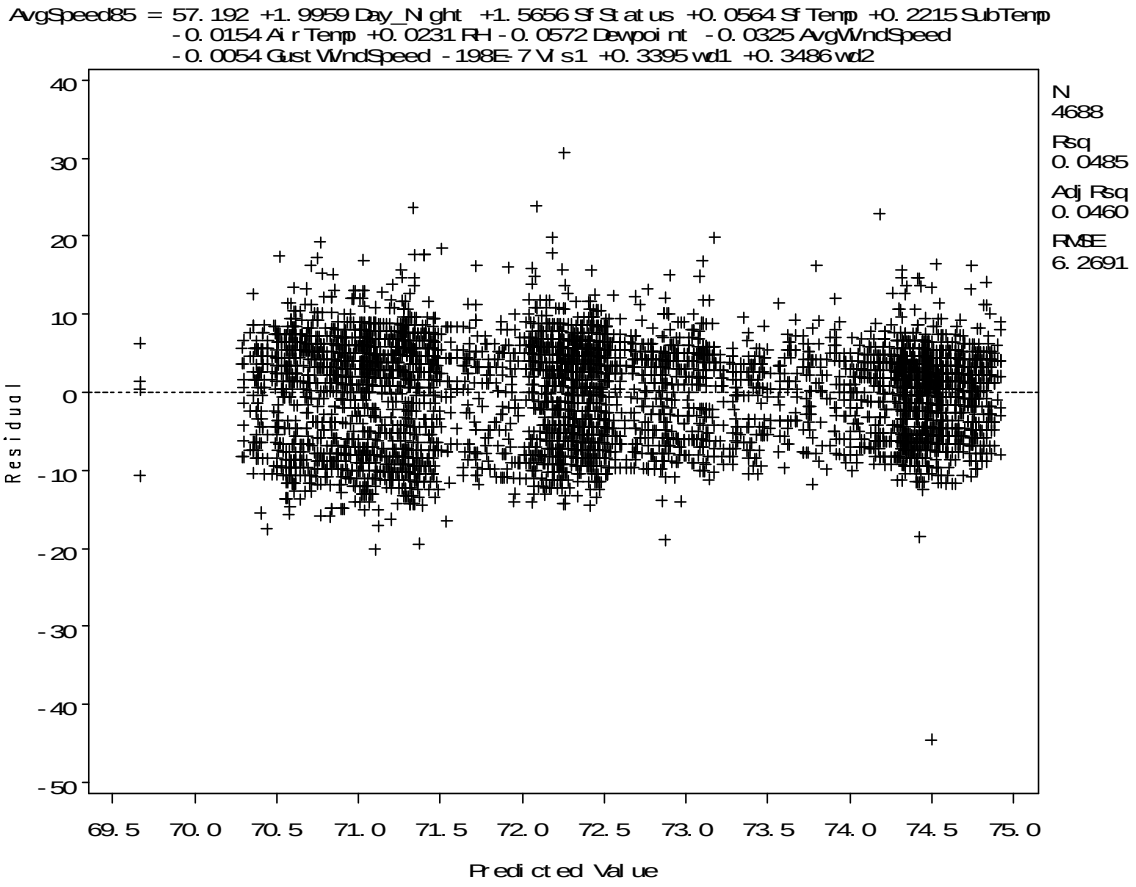
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	12	9360.01975	780.00165	19.85	<.0001
Error	4675	183736	39.30176		
Corrected Total	4687	193096			

Root MSE	6.26911	R-Square	0.0485
Dependent Mean	72.62585	Adj R-Sq	0.0460
Coeff Var	8.63207		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	57.19152	6.87780	8.32	<.0001	0
Day_Night	Day_Night	1	1.99586	0.32988	6.05	<.0001	3.24186
SfStatus	SfStatus	1	1.56561	2.27765	0.69	0.4919	1.05417
SfTemp	SfTemp	1	0.05640	0.01788	3.16	0.0016	6.43542
SubTemp	SubTemp	1	0.22155	0.10430	2.12	0.0337	3.31916
AirTemp	AirTemp	1	-0.01536	0.02923	-0.53	0.5993	7.56544
RH	RH	1	0.02310	0.00989	2.34	0.0196	3.31427
Dewpoint	Dewpoint	1	-0.05718	0.02127	-2.69	0.0072	4.47915
AvgWindSpeed	AvgWindSpeed	1	-0.03249	0.06072	-0.54	0.5926	11.05449
GustWindSpeed	GustWindSpeed	1	-0.00538	0.04905	-0.11	0.9127	11.53336
Vis1	Vis1	1	-0.00001982	0.00004572	-0.43	0.6647	2.63150
wd1		1	0.33947	2.25454	0.15	0.8803	151.57291
wd2		1	0.34855	2.25446	0.15	0.8771	151.55559


AvgSpeed85 = 57.192 +1.9959 Day_Night +1.5656 SfStatus +0.0564 SfTemp +0.2215 SubTemp
-0.0154 Air Temp +0.0231 RH -0.0572 Dewpoint -0.0325 AvgWndSpeed
-0.0054 Gust WndSpeed -198E-7 Vis1 +0.3395 wd1 +0.3486 wd2
N
4688
Rsq
0.0485
Adj Rsq
0.0460
RMSE
6.2691
Residual
Predicted Value
40
30
20
10
0
-10
-20
-30
-40
-50
69.5
70.0
70.5
71.0
71.5
72.0
72.5
73.0
73.5
74.0
74.5
75.0

Sensor 16 Minus Outliers Final Model

The SAS System 13:41 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	65535
Number of Observations Used	4688
Number of Observations with Missing Values	60847

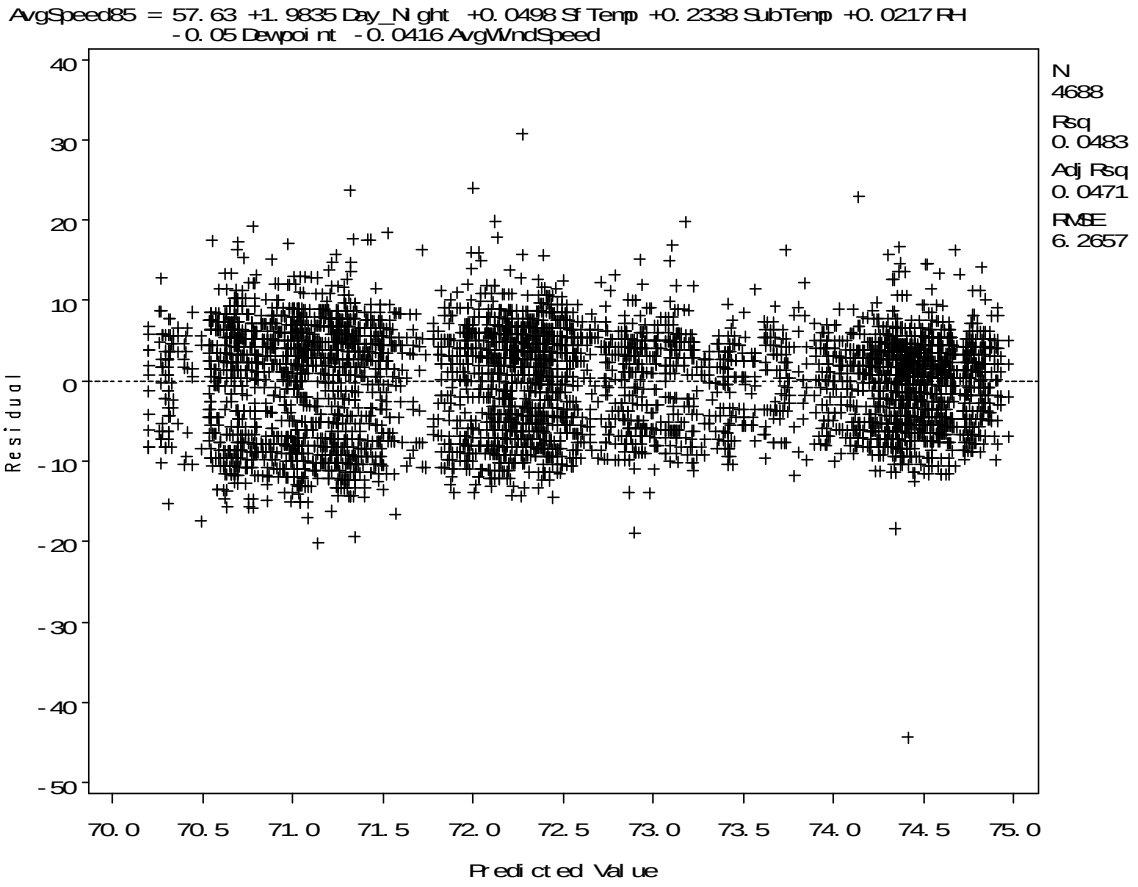
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	9325.51943	1554.25324	39.59	<.0001
Error	4681	183770	39.25875		
Corrected Total	4687	193096			

Root MSE	6.26568	R-Square	0.0483
Dependent Mean	72.62585	Adj R-Sq	0.0471
Coeff Var	8.62734		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	57.63039	4.78278	12.05	<.0001	0
Day_Night	Day_Night	1	1.98350	0.30056	6.60	<.0001	2.69416
SfTemp	SfTemp	1	0.04977	0.01037	4.80	<.0001	2.16887
SubTemp	SubTemp	1	0.23376	0.09275	2.52	0.0118	2.62766
RH	RH	1	0.02174	0.00931	2.34	0.0196	2.94070
Dewpoint	Dewpoint	1	-0.04998	0.01655	-3.02	0.0025	2.71680
AvgWindSpeed	AvgWindSpeed	1	-0.04156	0.02377	-1.75	0.0805	1.69605


AvgSpeed85 = 57.63 +1.9835 Day_Night +0.0498 Sf Temp +0.2338 SubTemp +0.0217 RH
-0.05 Dewpoint -0.0416 AvgWindSpeed
N
4688
Rsq
0.0483
Adj Rsq
0.0471
RMSE
6.2657
Residual
Predicted Value
40
30
20
10
0
-10
-20
-30
-40
-50
70.0
70.5
71.0
71.5
72.0
72.5
73.0
73.5
74.0
74.5
75.0

Sensor 17 Initial Model

The SAS System 13:53 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	5072
Number of Observations Used	4222
Number of Observations with Missing Values	850

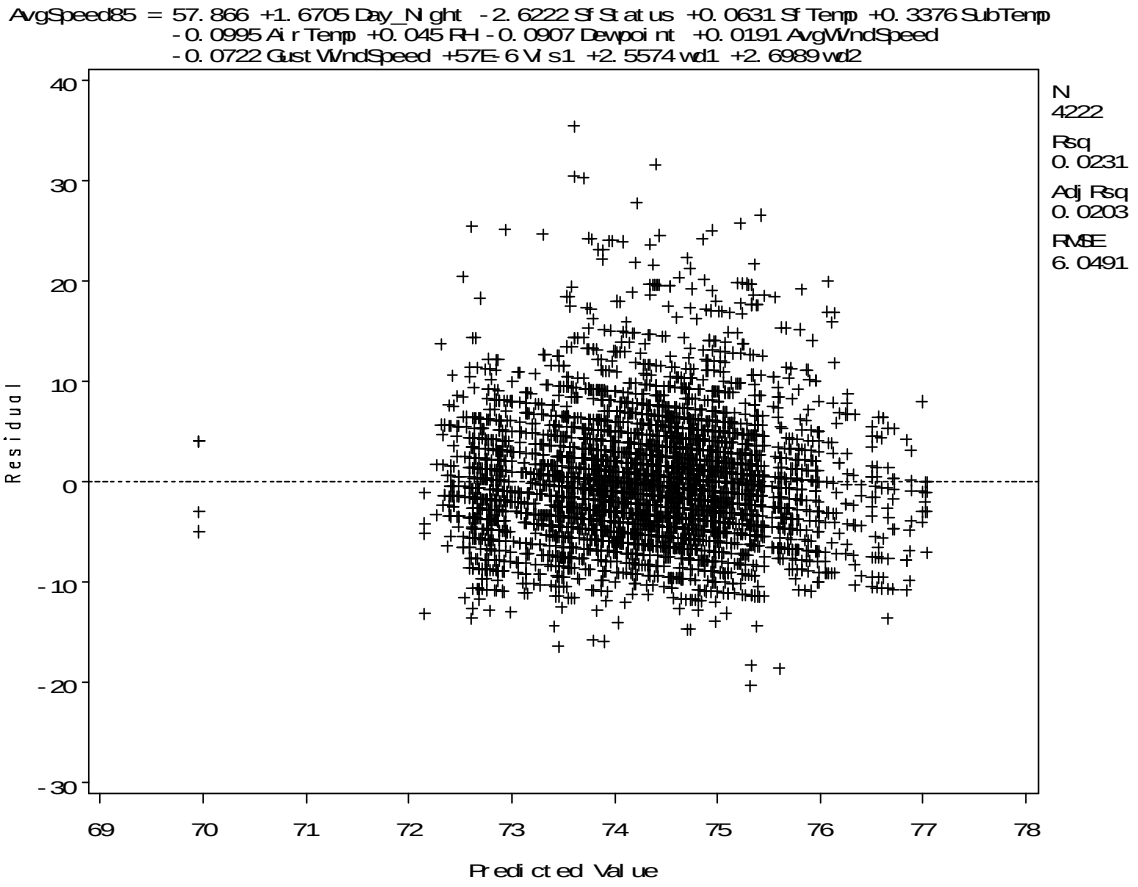
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	12	3641.65284	303.47107	8.29	<.0001
Error	4209	154012	36.59102		
Corrected Total	4221	157653			

Root MSE	6.04905	R-Square	0.0231
Dependent Mean	74.31904	Adj R-Sq	0.0203
Coeff Var	8.13930		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	57.86596	6.89490	8.39	<.0001	0
Day_Night	Day_Night	1	1.67054	0.33429	5.00	<.0001	3.22058
SfStatus	SfStatus	1	-2.62216	2.20284	-1.19	0.2340	1.05890
SfTemp	SfTemp	1	0.06311	0.01813	3.48	0.0005	6.52367
SubTemp	SubTemp	1	0.33758	0.10547	3.20	0.0014	3.28435
AirTemp	AirTemp	1	-0.09954	0.02958	-3.37	0.0008	7.60689
RH	RH	1	0.04504	0.01001	4.50	<.0001	3.34407
Dewpoint	Dewpoint	1	-0.09074	0.02167	-4.19	<.0001	4.38788
AvgWindSpeed	AvgWindSpeed	1	0.01912	0.06076	0.31	0.7529	10.93730
GustWindSpeed	GustWindSpeed	1	-0.07216	0.04903	-1.47	0.1411	11.43500
Vis1	Vis1	1	0.00005700	0.00004635	1.23	0.2189	2.57569
wd1		1	2.55740	2.17819	1.17	0.2404	136.68189
wd2		1	2.69889	2.17814	1.24	0.2154	136.71170


AvgSpeed85 = 57.866 +1.6705 Day_Night -2.6222 SfStatus +0.0631 SfTemp +0.3376 SubTemp
-0.0995 AirTemp +0.045 RH -0.0907 Dewpoint +0.0191 AvgWindSpeed
-0.0722 GustWindSpeed +57E-6 Vis1 +2.5574 wd1 +2.6989 wd2
N
4222
Rsq
0.0231
Adj Rsq
0.0203
RMSE
6.0491
Residual
Predicted Value
40
30
20
10
0
-10
-20
-30
69
70
71
72
73
74
75
76
77
78

Sensor 17 Final Model

The SAS System 13:53 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	5072
Number of Observations Used	4222
Number of Observations with Missing Values	850

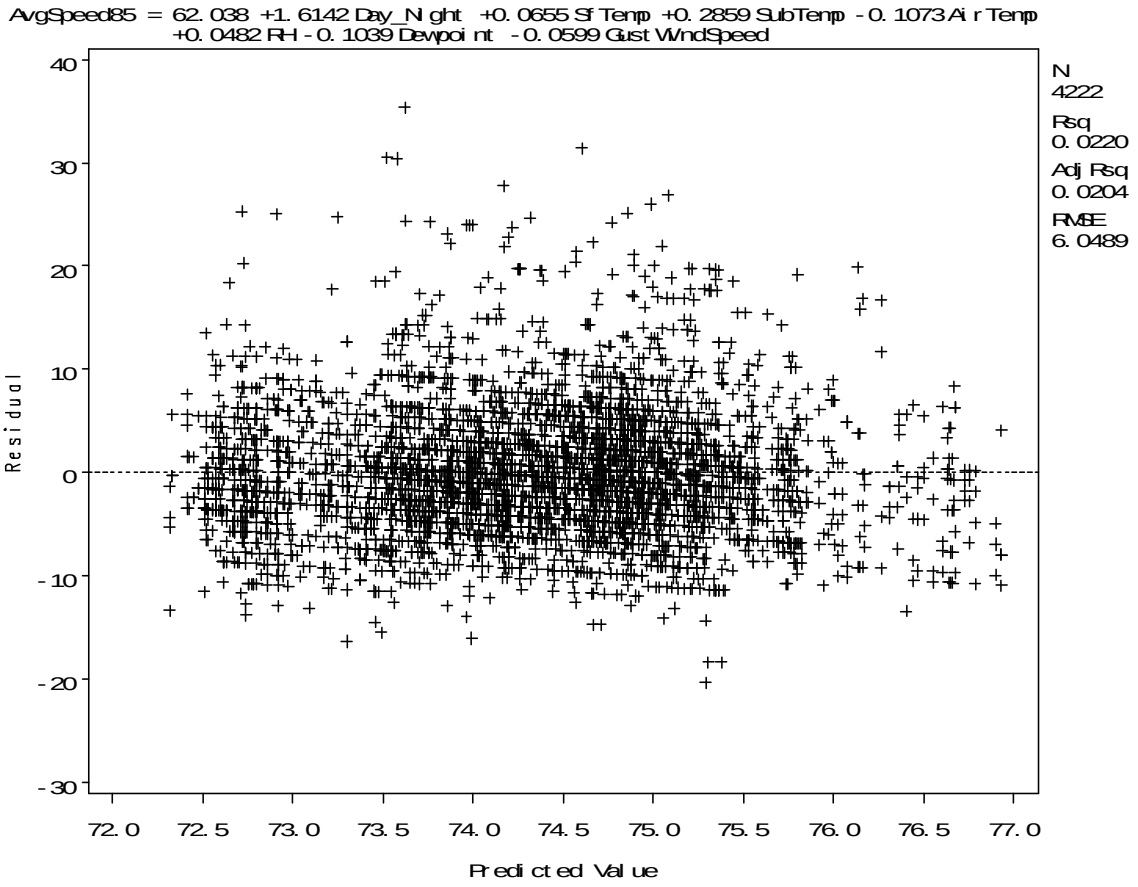
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	3468.80490	495.54356	13.54	<.0001
Error	4214	154184	36.58862		
Corrected Total	4221	157653			

Root MSE	6.04885	R-Square	0.0220
Dependent Mean	74.31904	Adj R-Sq	0.0204
Coeff Var	8.13903		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	62.03824	4.77408	12.99	<.0001	0
Day_Night	Day_Night	1	1.61418	0.31938	5.05	<.0001	2.93981
SfTemp	SfTemp	1	0.06554	0.01734	3.78	0.0002	5.96695
SubTemp	SubTemp	1	0.28592	0.09366	3.05	0.0023	2.59010
AirTemp	AirTemp	1	-0.10731	0.02883	-3.72	0.0002	7.22817
RH	RH	1	0.04821	0.00955	5.05	<.0001	3.04604
Dewpoint	Dewpoint	1	-0.10385	0.01792	-5.80	<.0001	2.99954
GustWindSpeed	GustWindSpeed	1	-0.05988	0.01995	-3.00	0.0027	1.89289


AvgSpeed85 = 62.038 +1.6142 Day_Night +0.0655 Sf Temp +0.2859 SubTemp -0.1073 Air Temp
+0.0482 RH -0.1039 Dewpoint -0.0599 Gust WindSpeed
N
4222
Rsq
0.0220
Adj Rsq
0.0204
RMSE
6.0489
Residual
Predicted Value
40
30
20
10
0
-10
-20
-30
72.0
72.5
73.0
73.5
74.0
74.5
75.0
75.5
76.0
76.5
77.0

Sensor 17 Minus Outliers Initial Model

The SAS System 13:57 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	5072
Number of Observations Used	4222
Number of Observations with Missing Values	850

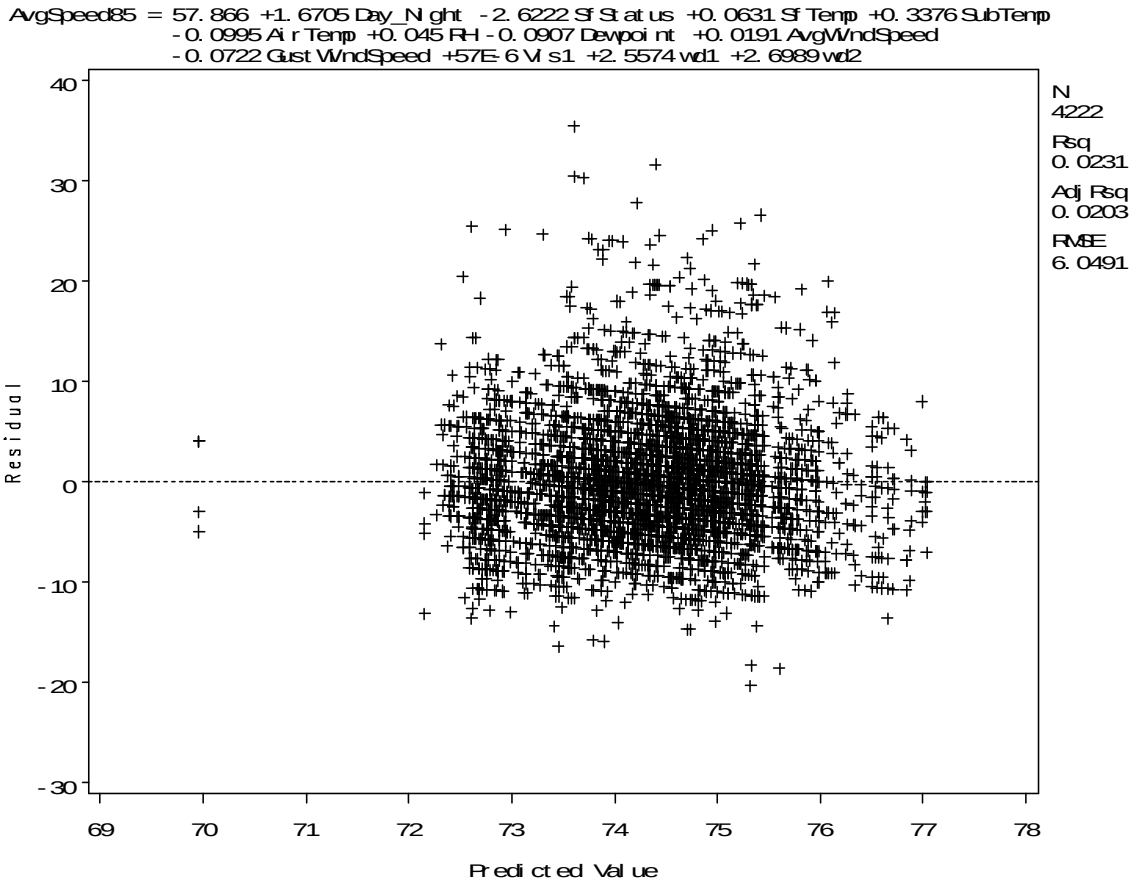
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	12	3641.65284	303.47107	8.29	<.0001
Error	4209	154012	36.59102		
Corrected Total	4221	157653			

Root MSE	6.04905	R-Square	0.0231
Dependent Mean	74.31904	Adj R-Sq	0.0203
Coeff Var	8.13930		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	57.86596	6.89490	8.39	<.0001	0
Day_Night	Day_Night	1	1.67054	0.33429	5.00	<.0001	3.22058
SfStatus	SfStatus	1	-2.62216	2.20284	-1.19	0.2340	1.05890
SfTemp	SfTemp	1	0.06311	0.01813	3.48	0.0005	6.52367
SubTemp	SubTemp	1	0.33758	0.10547	3.20	0.0014	3.28435
AirTemp	AirTemp	1	-0.09954	0.02958	-3.37	0.0008	7.60689
RH	RH	1	0.04504	0.01001	4.50	<.0001	3.34407
Dewpoint	Dewpoint	1	-0.09074	0.02167	-4.19	<.0001	4.38788
AvgWindSpeed	AvgWindSpeed	1	0.01912	0.06076	0.31	0.7529	10.93730
GustWindSpeed	GustWindSpeed	1	-0.07216	0.04903	-1.47	0.1411	11.43500
Vis1	Vis1	1	0.00005700	0.00004635	1.23	0.2189	2.57569
wd1		1	2.55740	2.17819	1.17	0.2404	136.68189
wd2		1	2.69889	2.17814	1.24	0.2154	136.71170


AvgSpeed85 = 57.866 +1.6705 Day_Night -2.6222 SfStatus +0.0631 SfTemp +0.3376 SubTemp
-0.0995 AirTemp +0.045 RH -0.0907 Dewpoint +0.0191 AvgWndSpeed
-0.0722 GustWndSpeed +57E-6 Vis1 +2.5574 wd1 +2.6989 wd2
N
4222
Rsq
0.0231
Adj Rsq
0.0203
RMSE
6.0491
Residual
Predicted Value
40
30
20
10
0
-10
-20
-30
69
70
71
72
73
74
75
76
77
78

Sensor 17 Minus Outliers Final Model

The SAS System 13:57 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	5072
Number of Observations Used	4222
Number of Observations with Missing Values	850

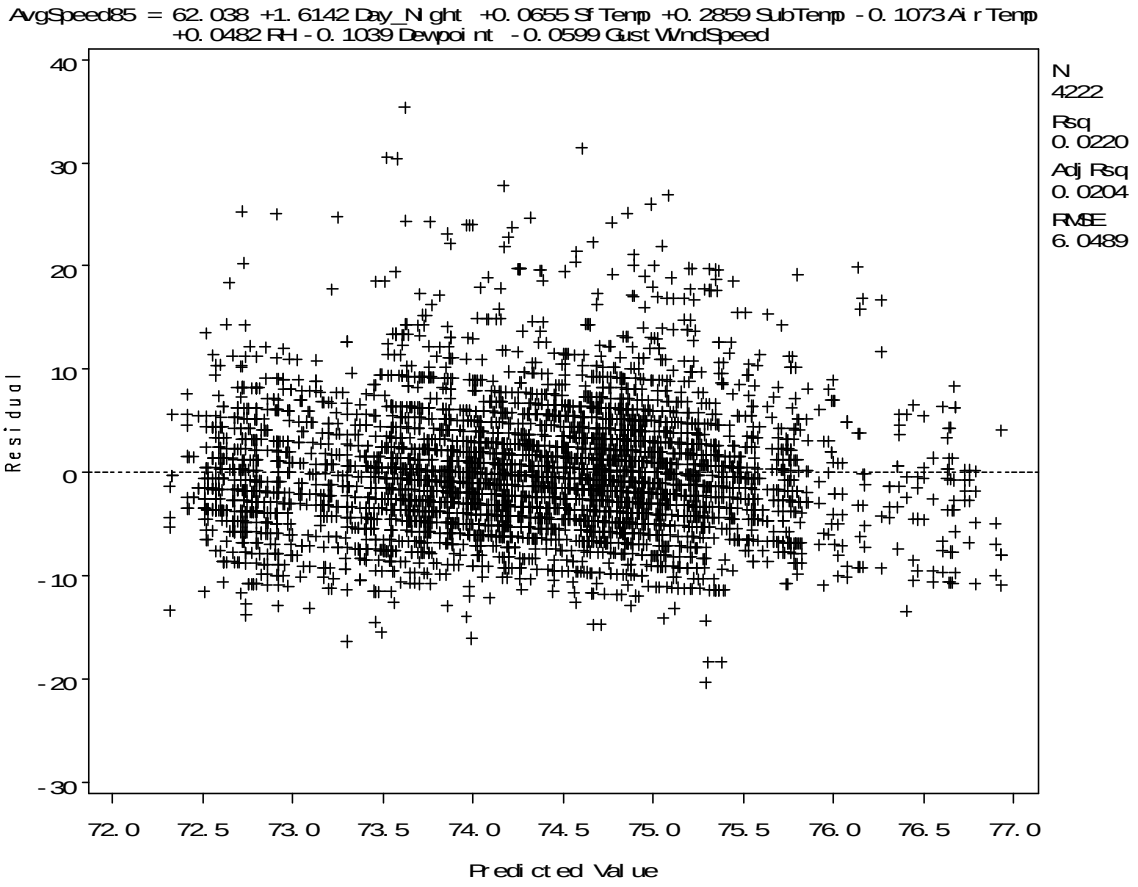
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	3468.80490	495.54356	13.54	<.0001
Error	4214	154184	36.58862		
Corrected Total	4221	157653			

Root MSE	6.04885	R-Square	0.0220
Dependent Mean	74.31904	Adj R-Sq	0.0204
Coeff Var	8.13903		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	62.03824	4.77408	12.99	<.0001	0
Day_Night	Day_Night	1	1.61418	0.31938	5.05	<.0001	2.93981
SfTemp	SfTemp	1	0.06554	0.01734	3.78	0.0002	5.96695
SubTemp	SubTemp	1	0.28592	0.09366	3.05	0.0023	2.59010
AirTemp	AirTemp	1	-0.10731	0.02883	-3.72	0.0002	7.22817
RH	RH	1	0.04821	0.00955	5.05	<.0001	3.04604
Dewpoint	Dewpoint	1	-0.10385	0.01792	-5.80	<.0001	2.99954
GustWindSpeed	GustWindSpeed	1	-0.05988	0.01995	-3.00	0.0027	1.89289


AvgSpeed85 = 62.038 +1.6142 Day_Night +0.0655 Sf Temp +0.2859 SubTemp -0.1073 Air Temp
+0.0482 RH -0.1039 Dewpoint -0.0599 Gust WindSpeed
N
4222
Rsq
0.0220
Adj Rsq
0.0204
RMSE
6.0489
Residual
40
30
20
10
0
-10
-20
-30
72.0
72.5
73.0
73.5
74.0
74.5
75.0
75.5
76.0
76.5
77.0
Predicted Value

Sensor 18 Initial Model

The SAS System 14:02 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	5087
Number of Observations Used	4631
Number of Observations with Missing Values	456

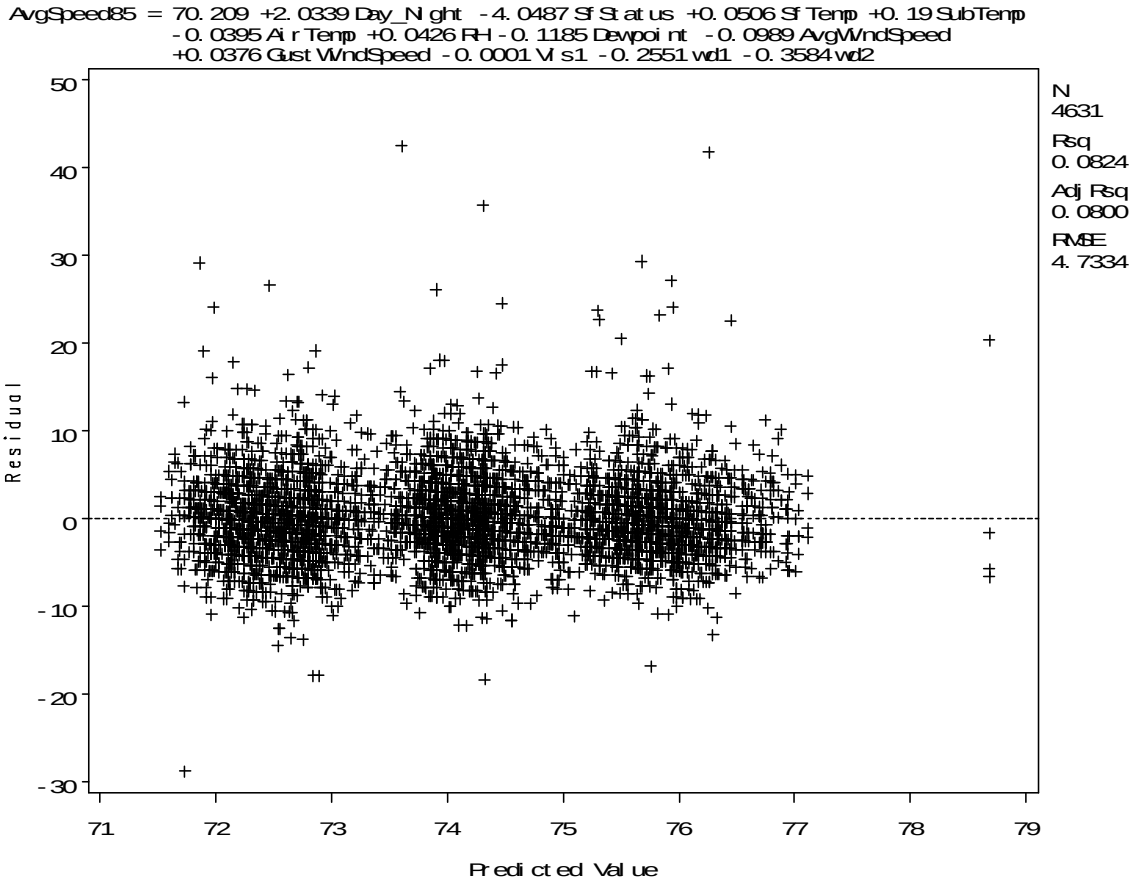
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	12	9287.41918	773.95160	34.54	<.0001
Error	4618	103469	22.40551		
Corrected Total	4630	112756			

Root MSE	4.73345	R-Square	0.0824
Dependent Mean	74.14317	Adj R-Sq	0.0800
Coeff Var	6.38420		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	70.20949	5.22875	13.43	<.0001	0
Day_Night	Day_Night	1	2.03388	0.24927	8.16	<.0001	3.20993
SfStatus	SfStatus	1	-4.04866	1.83733	-2.20	0.0276	1.05307
SfTemp	SfTemp	1	0.05064	0.01357	3.73	0.0002	6.44808
SubTemp	SubTemp	1	0.18996	0.07892	2.41	0.0161	3.29048
AirTemp	AirTemp	1	-0.03947	0.02212	-1.78	0.0744	7.50170
RH	RH	1	0.04257	0.00752	5.66	<.0001	3.32736
Dewpoint	Dewpoint	1	-0.11846	0.01623	-7.30	<.0001	4.47058
AvgWindSpeed	AvgWindSpeed	1	-0.09888	0.04601	-2.15	0.0317	11.01436
GustWindSpeed	GustWindSpeed	1	0.03763	0.03717	1.01	0.3113	11.48932
Vis1	Vis1	1	-0.00011209	0.00003467	-3.23	0.0012	2.62364
wd1		1	-0.25514	1.70249	-0.15	0.8809	149.76801
wd2		1	-0.35838	1.70240	-0.21	0.8333	149.75504


AvgSpeed85 = 70.209 +2.0339 Day_Night -4.0487 SfStatus +0.0506 SfTemp +0.19 SubTemp
-0.0395 AirTemp +0.0426 RH -0.1185 Dewpoint -0.0989 AvgWndSpeed
+0.0376 GustWndSpeed -0.0001 Vis1 -0.2551 wd1 -0.3584 wd2
N
4631
Rsq
0.0824
Adj Rsq
0.0800
RMSE
4.7334
Residual
Predicted Value
50
40
30
20
10
0
-10
-20
-30
71
72
73
74
75
76
77
78
79

Sensor 18 Final Model

The SAS System 14:02 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	5087
Number of Observations Used	4631
Number of Observations with Missing Values	456

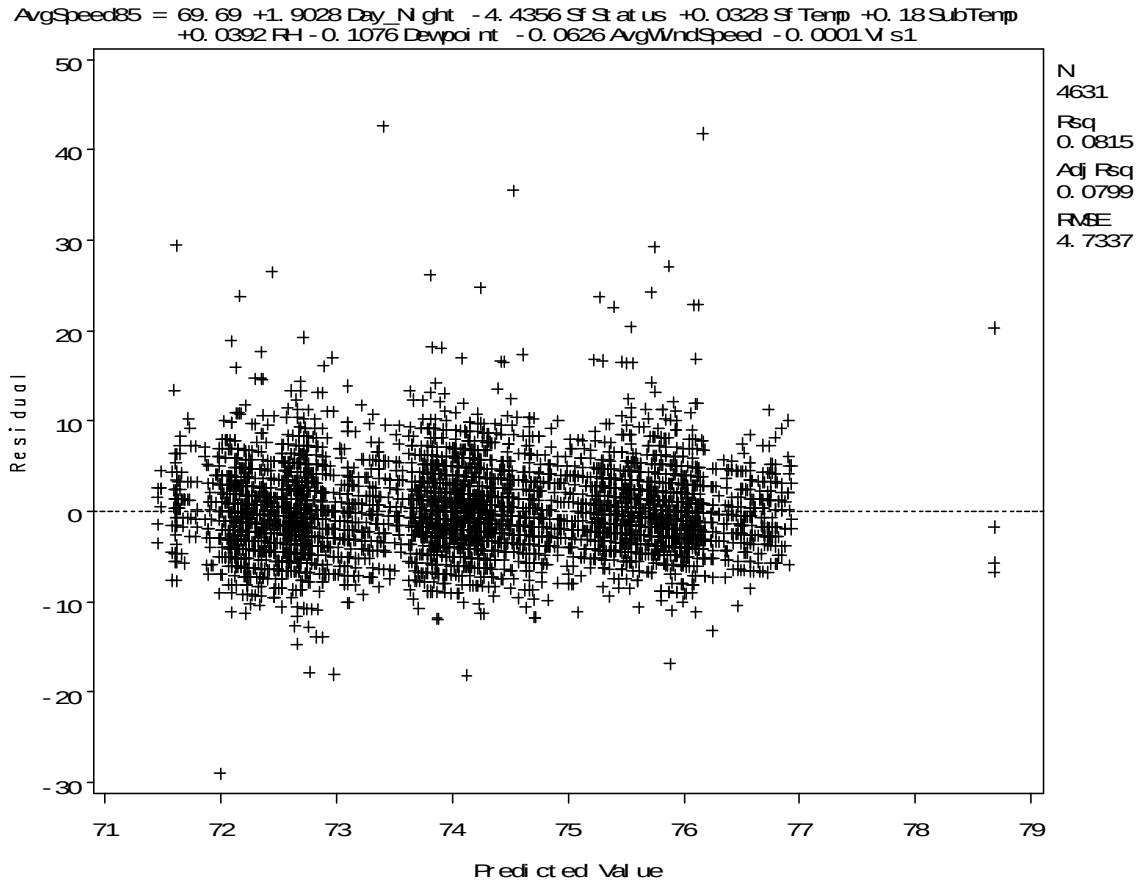
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	9187.23388	1148.40423	51.25	<.0001
Error	4622	103569	22.40780		
Corrected Total	4630	112756			

Root MSE	4.73369	R-Square	0.0815
Dependent Mean	74.14317	Adj R-Sq	0.0799
Coeff Var	6.38452		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	69.68967	4.82254	14.45	<.0001	0
Day_Night	Day_Night	1	1.90280	0.23594	8.06	<.0001	2.87547
SfStatus	SfStatus	1	-4.43562	1.81267	-2.45	0.0144	1.02490
SfTemp	SfTemp	1	0.03275	0.00815	4.02	<.0001	2.32783
SubTemp	SubTemp	1	0.18000	0.07841	2.30	0.0217	3.24794
RH	RH	1	0.03919	0.00716	5.47	<.0001	3.01719
Dewpoint	Dewpoint	1	-0.10756	0.01486	-7.24	<.0001	3.74882
AvgWindSpeed	AvgWindSpeed	1	-0.06260	0.01841	-3.40	0.0007	1.76282
Vis1	Vis1	1	-0.00009840	0.00003374	-2.92	0.0036	2.48396


AvgSpeed85 = 69.69 +1.9028 Day_Night -4.4356 SfStatus +0.0328 SfTemp +0.18 SubTemp
+0.0392 RH -0.1076 Dewpoint -0.0626 AvgWindSpeed -0.0001 Vis1
N
4631
Rsq
0.0815
Adj Rsq
0.0799
RMSE
4.7337
Residual
Predicted Value
50
40
30
20
10
0
-10
-20
-30
71
72
73
74
75
76
77
78
79

Sensor 18 Minus Outliers Initial Model

The SAS System 14:06 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	5087
Number of Observations Used	4631
Number of Observations with Missing Values	456

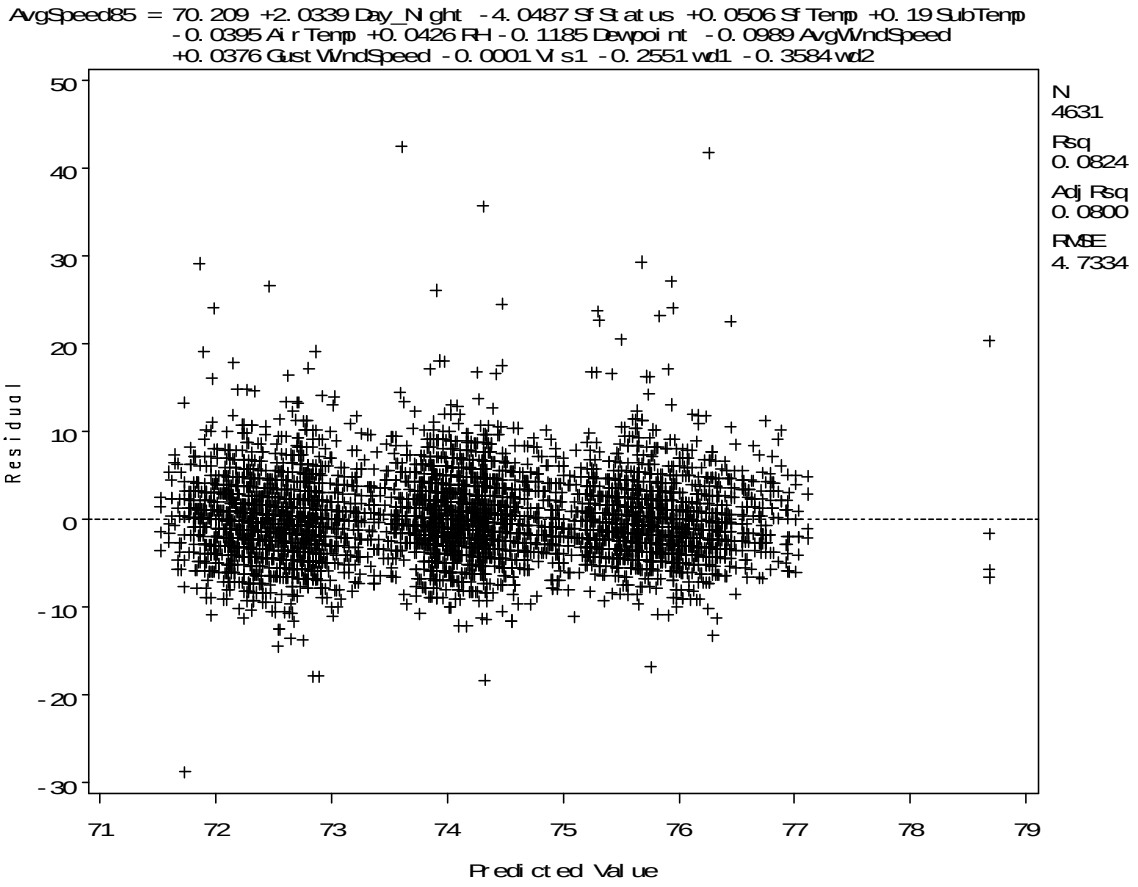
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	12	9287.41918	773.95160	34.54	<.0001
Error	4618	103469	22.40551		
Corrected Total	4630	112756			

Root MSE	4.73345	R-Square	0.0824
Dependent Mean	74.14317	Adj R-Sq	0.0800
Coeff Var	6.38420		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	70.20949	5.22875	13.43	<.0001	0
Day_Night	Day_Night	1	2.03388	0.24927	8.16	<.0001	3.20993
SfStatus	SfStatus	1	-4.04866	1.83733	-2.20	0.0276	1.05307
SfTemp	SfTemp	1	0.05064	0.01357	3.73	0.0002	6.44808
SubTemp	SubTemp	1	0.18996	0.07892	2.41	0.0161	3.29048
AirTemp	AirTemp	1	-0.03947	0.02212	-1.78	0.0744	7.50170
RH	RH	1	0.04257	0.00752	5.66	<.0001	3.32736
Dewpoint	Dewpoint	1	-0.11846	0.01623	-7.30	<.0001	4.47058
AvgWindSpeed	AvgWindSpeed	1	-0.09888	0.04601	-2.15	0.0317	11.01436
GustWindSpeed	GustWindSpeed	1	0.03763	0.03717	1.01	0.3113	11.48932
Vis1	Vis1	1	-0.00011209	0.00003467	-3.23	0.0012	2.62364
wd1		1	-0.25514	1.70249	-0.15	0.8809	149.76801
wd2		1	-0.35838	1.70240	-0.21	0.8333	149.75504


AvgSpeed85 = 70.209 +2.0339 Day_Night -4.0487 SfStatus +0.0506 SfTemp +0.19 SubTemp
-0.0395 Air Temp +0.0426 RH -0.1185 Dewpoint -0.0989 AvgWndSpeed
+0.0376 GustWndSpeed -0.0001 Vis1 -0.2551 wd1 -0.3584 wd2
N
4631
Rsq
0.0824
Adj Rsq
0.0800
RMSE
4.7334
Residual
Predicted Value
50
40
30
20
10
0
-10
-20
-30
71
72
73
74
75
76
77
78
79

Sensor 18 Minus Outliers Final Model

The SAS System 14:06 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	5087
Number of Observations Used	4631
Number of Observations with Missing Values	456

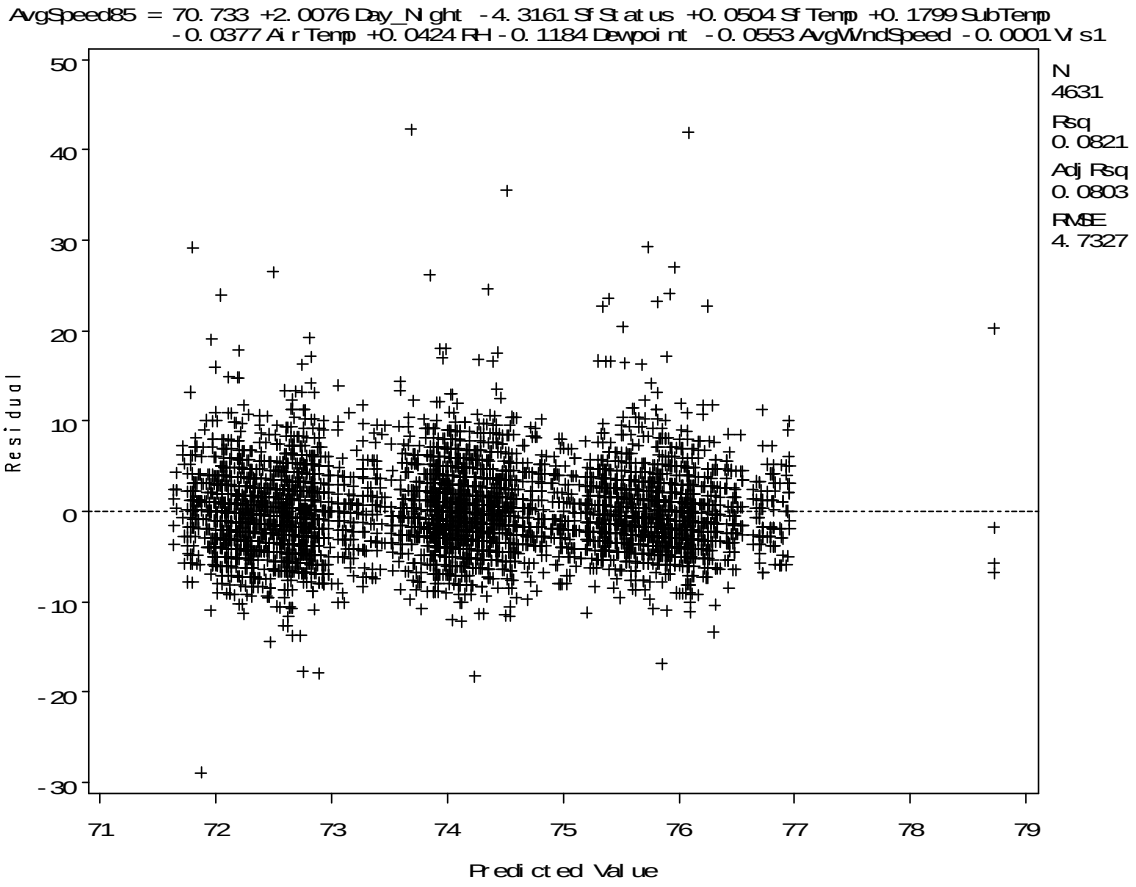
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	9253.12227	1028.12470	45.90	<.0001
Error	4621	103503	22.39839		
Corrected Total	4630	112756			

Root MSE	4.73269	R-Square	0.0821
Dependent Mean	74.14317	Adj R-Sq	0.0803
Coeff Var	6.38318		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	70.73268	4.85973	14.55	<.0001	0
Day_Night	Day_Night	1	2.00756	0.24367	8.24	<.0001	3.06825
SfStatus	SfStatus	1	-4.31609	1.81363	-2.38	0.0174	1.02641
SfTemp	SfTemp	1	0.05038	0.01312	3.84	0.0001	6.03162
SubTemp	SubTemp	1	0.17988	0.07839	2.29	0.0218	3.24794
AirTemp	AirTemp	1	-0.03775	0.02201	-1.72	0.0864	7.43074
RH	RH	1	0.04238	0.00740	5.73	<.0001	3.22107
Dewpoint	Dewpoint	1	-0.11837	0.01614	-7.33	<.0001	4.42347
AvgWindSpeed	AvgWindSpeed	1	-0.05532	0.01889	-2.93	0.0034	1.85662
Vis1	Vis1	1	-0.00011198	0.00003465	-3.23	0.0012	2.62078


AvgSpeed85 = 70.733 +2.0076 Day_Night -4.3161 SfStatus +0.0504 SfTemp +0.1799 SubTemp
-0.0377 AirTemp +0.0424 RH -0.1184 Dewpoint -0.0553 AvgWndSpeed -0.0001 Vis1
N
4631
Rsq
0.0821
Adj Rsq
0.0803
RMSE
4.7327
Residual
Predicted Value
50
40
30
20
10
0
-10
-20
-30
71
72
73
74
75
76
77
78
79

Sensor 19 Initial Model

The SAS System 14:09 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	5088
Number of Observations Used	4543
Number of Observations with Missing Values	545

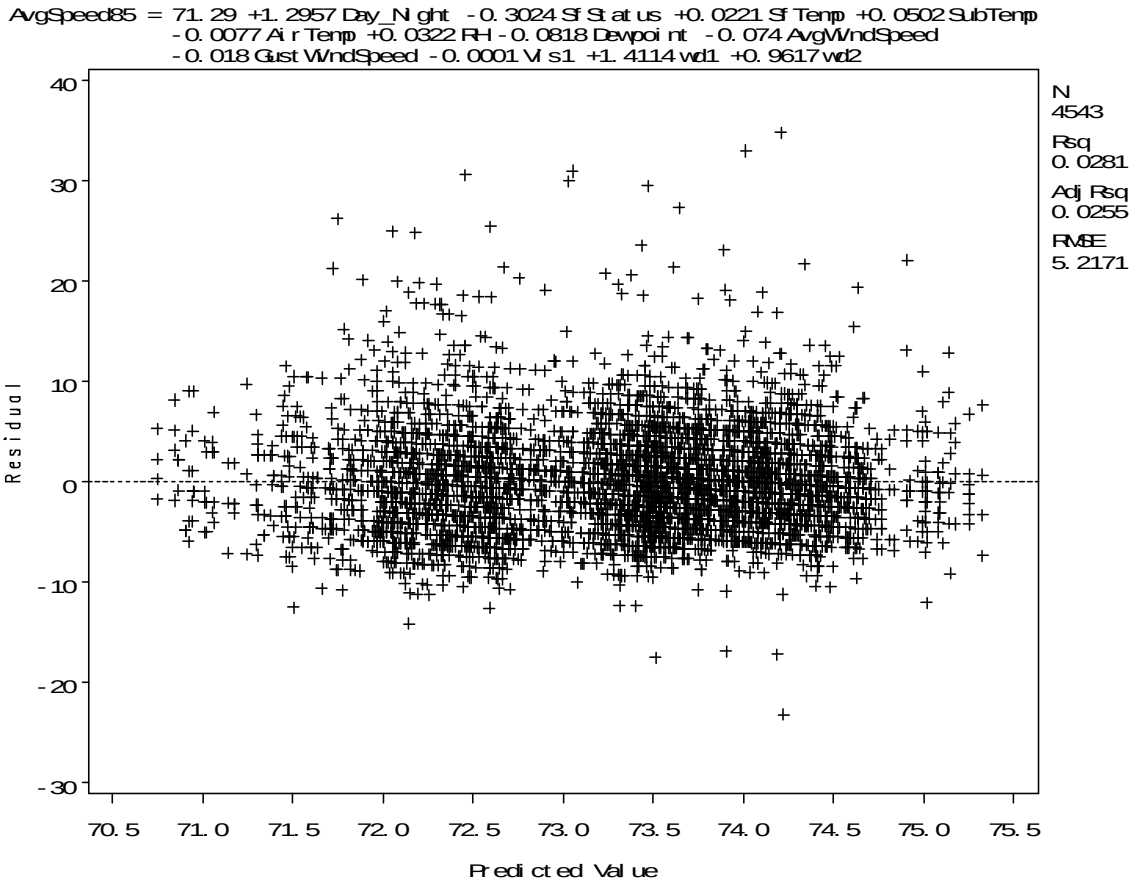
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	12	3564.92295	297.07691	10.91	<.0001
Error	4530	123299	27.21826		
Corrected Total	4542	126864			

Root MSE	5.21711	R-Square	0.0281
Dependent Mean	73.29870	Adj R-Sq	0.0255
Coeff Var	7.11761		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	71.29021	5.79854	12.29	<.0001	0
Day_Night	Day_Night	1	1.29568	0.27736	4.67	<.0001	3.21002
SfStatus	SfStatus	1	-0.30238	2.02558	-0.15	0.8813	1.05358
SfTemp	SfTemp	1	0.02210	0.01504	1.47	0.1417	6.44413
SubTemp	SubTemp	1	0.05022	0.08767	0.57	0.5668	3.28128
AirTemp	AirTemp	1	-0.00773	0.02457	-0.31	0.7529	7.51344
RH	RH	1	0.03219	0.00836	3.85	0.0001	3.34064
Dewpoint	Dewpoint	1	-0.08179	0.01806	-4.53	<.0001	4.46985
AvgWindSpeed	AvgWindSpeed	1	-0.07402	0.05089	-1.45	0.1459	10.97138
GustWindSpeed	GustWindSpeed	1	-0.01800	0.04104	-0.44	0.6610	11.42908
Vis1	Vis1	1	-0.00006768	0.00003857	-1.75	0.0793	2.60520
wd1		1	1.41138	1.87669	0.75	0.4521	146.92237
wd2		1	0.96168	1.87659	0.51	0.6084	146.92267


AvgSpeed85 = 71.29 +1.2957 Day_Night -0.3024 SfStatus +0.0221 SfTemp +0.0502 SubTemp
-0.0077 AirTemp +0.0322 RH -0.0818 Dewpoint -0.074 AvgWindSpeed
-0.018 GustWindSpeed -0.0001 Vis1 +1.4114 wd1 +0.9617 wd2
N
4543
Rsq
0.0281
Adj Rsq
0.0255
RMSE
5.2171
Residual
Predicted Value
40
30
20
10
0
-10
-20
-30
70.5
71.0
71.5
72.0
72.5
73.0
73.5
74.0
74.5
75.0
75.5

Sensor 19 Final Model

The SAS System 14:09 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	5088
Number of Observations Used	4558
Number of Observations with Missing Values	530

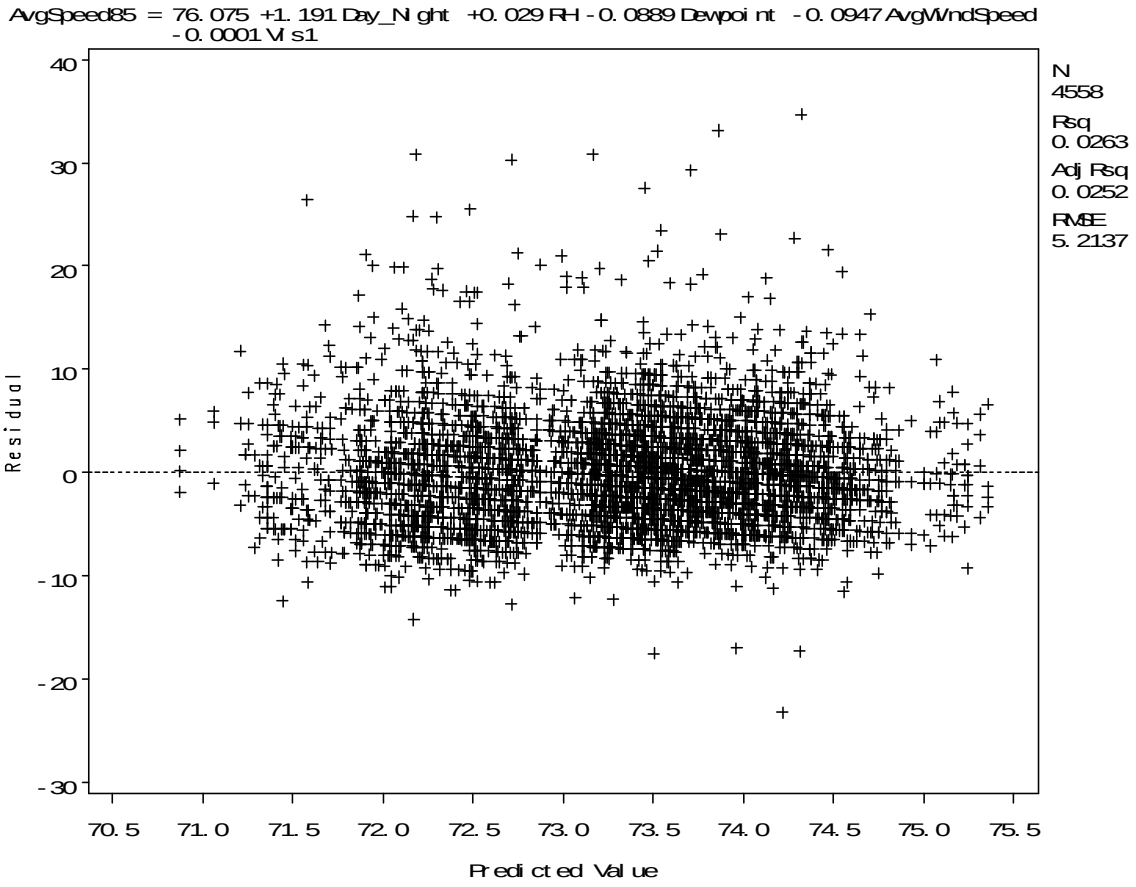
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	3336.98653	667.39731	24.55	<.0001
Error	4552	123733	27.18217		
Corrected Total	4557	127070			

Root MSE	5.21365	R-Square	0.0263
Dependent Mean	73.30057	Adj R-Sq	0.0252
Coeff Var	7.11270		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	76.07525	0.74756	101.77	<.0001	0
Day_Night	Day_Night	1	1.19097	0.16996	7.01	<.0001	1.21089
RH	RH	1	0.02898	0.00747	3.88	0.0001	2.68065
Dewpoint	Dewpoint	1	-0.08888	0.01506	-5.90	<.0001	3.12222
AvgWindSpeed	AvgWindSpeed	1	-0.09469	0.01743	-5.43	<.0001	1.29652
Vis1	Vis1	1	-0.00008677	0.00003130	-2.77	0.0056	1.72469


AvgSpeed85 = 76.075 +1.191 Day_Night +0.029 RH -0.0889 Dewpoint -0.0947 AvgWndSpeed
-0.0001 Vis1
N
4558
Rsq
0.0263
Adj Rsq
0.0252
RMSE
5.2137
Residual
Predicted Value
40
30
20
10
0
-10
-20
-30
70.5
71.0
71.5
72.0
72.5
73.0
73.5
74.0
74.5
75.0
75.5

Sensor 19 Minus Outliers Initial Model

The SAS System 14:12 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	5088
Number of Observations Used	4543
Number of Observations with Missing Values	545

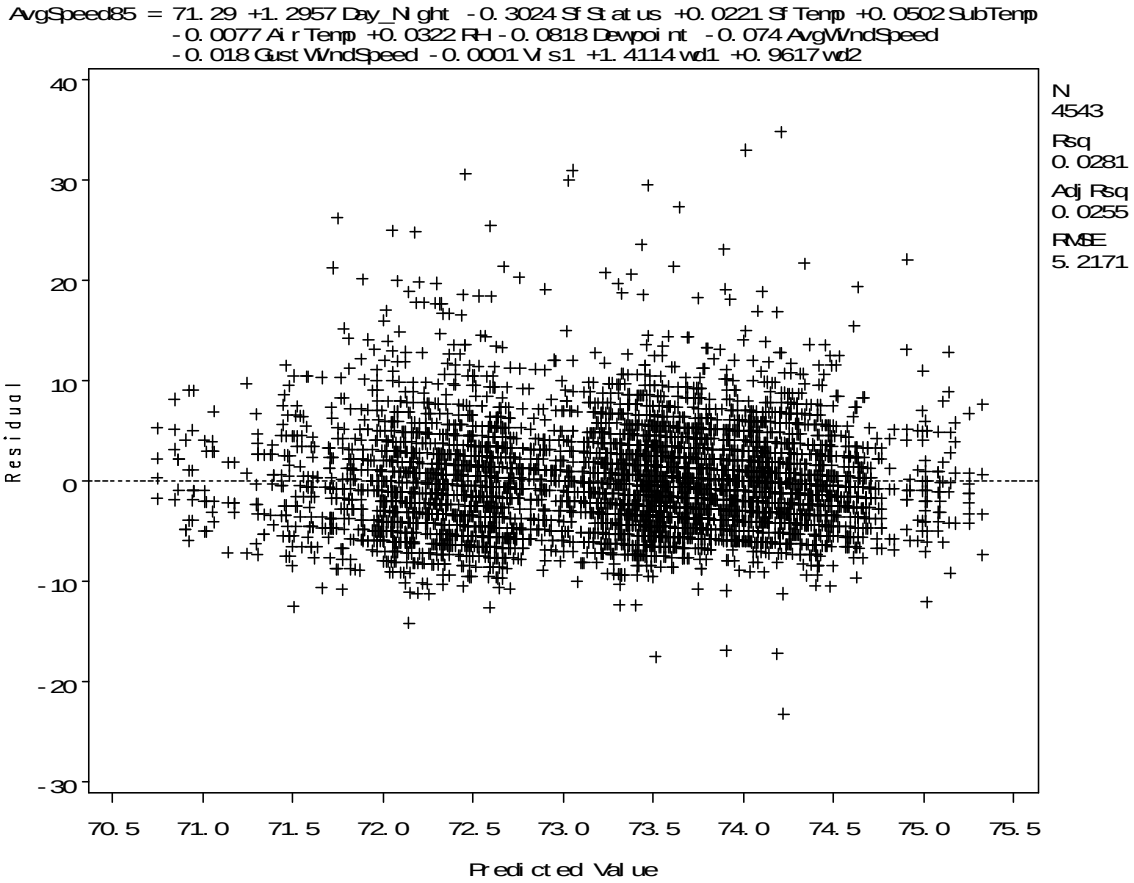
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	12	3564.92295	297.07691	10.91	<.0001
Error	4530	123299	27.21826		
Corrected Total	4542	126864			

Root MSE	5.21711	R-Square	0.0281
Dependent Mean	73.29870	Adj R-Sq	0.0255
Coeff Var	7.11761		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	71.29021	5.79854	12.29	<.0001	0
Day_Night	Day_Night	1	1.29568	0.27736	4.67	<.0001	3.21002
SfStatus	SfStatus	1	-0.30238	2.02558	-0.15	0.8813	1.05358
SfTemp	SfTemp	1	0.02210	0.01504	1.47	0.1417	6.44413
SubTemp	SubTemp	1	0.05022	0.08767	0.57	0.5668	3.28128
AirTemp	AirTemp	1	-0.00773	0.02457	-0.31	0.7529	7.51344
RH	RH	1	0.03219	0.00836	3.85	0.0001	3.34064
Dewpoint	Dewpoint	1	-0.08179	0.01806	-4.53	<.0001	4.46985
AvgWindSpeed	AvgWindSpeed	1	-0.07402	0.05089	-1.45	0.1459	10.97138
GustWindSpeed	GustWindSpeed	1	-0.01800	0.04104	-0.44	0.6610	11.42908
Vis1	Vis1	1	-0.00006768	0.00003857	-1.75	0.0793	2.60520
wd1		1	1.41138	1.87669	0.75	0.4521	146.92237
wd2		1	0.96168	1.87659	0.51	0.6084	146.92267


AvgSpeed85 = 71.29 +1.2957 Day_Night -0.3024 SfStatus +0.0221 SfTemp +0.0502 SubTemp
-0.0077 AirTemp +0.0322 RH -0.0818 Dewpoint -0.074 AvgWndSpeed
-0.018 GustWndSpeed -0.0001 Vis1 +1.4114 wd1 +0.9617 wd2
N
4543
Rsq
0.0281
Adj Rsq
0.0255
RMSE
5.2171
Residual
40
30
20
10
0
-10
-20
-30
70.5
71.0
71.5
72.0
72.5
73.0
73.5
74.0
74.5
75.0
75.5
Predicted Value

Sensor 19 Minus Outliers Final Model

The SAS System 14:12 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	5088
Number of Observations Used	4543
Number of Observations with Missing Values	545

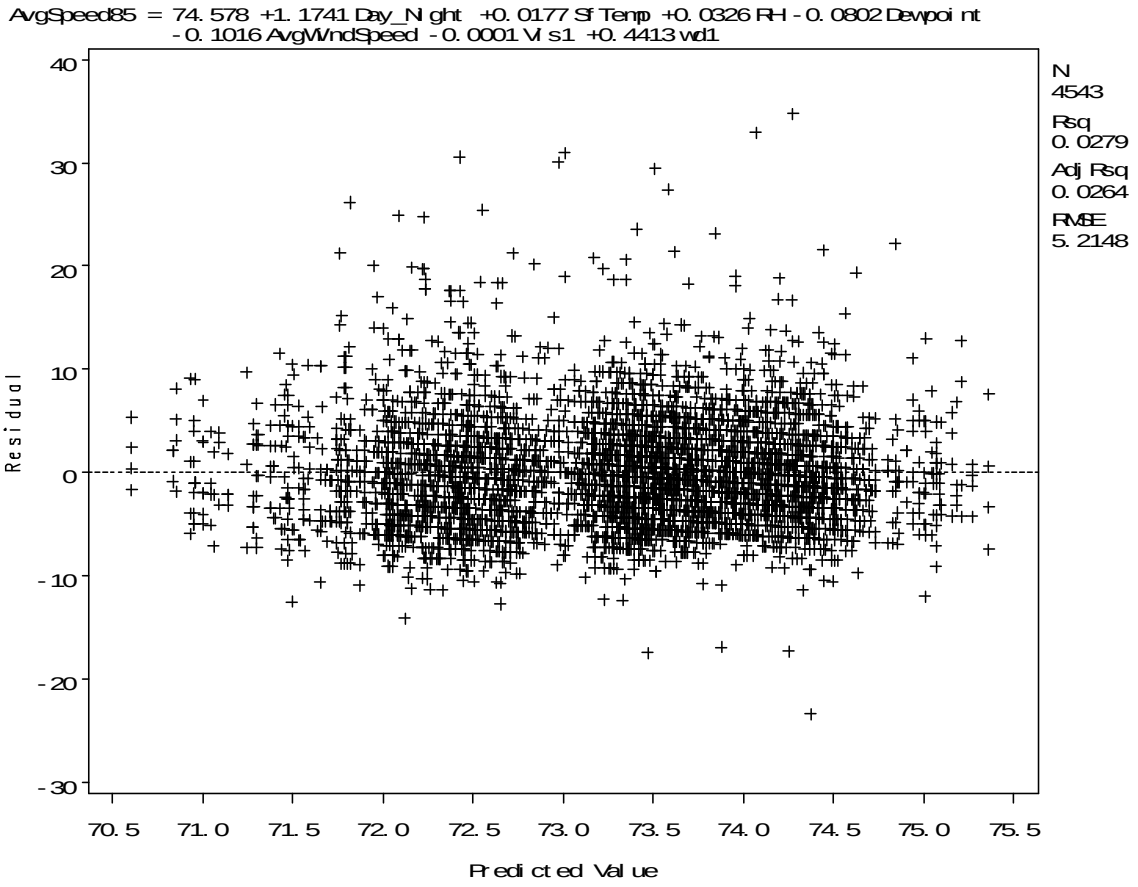
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	3536.52391	505.21770	18.58	<.0001
Error	4535	123327	27.19452		
Corrected Total	4542	126864			

Root MSE	5.21484	R-Square	0.0279
Dependent Mean	73.29870	Adj R-Sq	0.0264
Coeff Var	7.11450		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	74.57819	1.08907	68.48	<.0001	0
Day_Night	Day_Night	1	1.17409	0.21930	5.35	<.0001	2.00851
SfTemp	SfTemp	1	0.01766	0.00972	1.82	0.0692	2.69433
RH	RH	1	0.03262	0.00769	4.24	<.0001	2.82852
Dewpoint	Dewpoint	1	-0.08017	0.01653	-4.85	<.0001	3.74590
AvgWindSpeed	AvgWindSpeed	1	-0.10158	0.01782	-5.70	<.0001	1.34636
Vis1	Vis1	1	-0.00007500	0.00003336	-2.25	0.0246	1.95084
wd1		1	0.44133	0.20121	2.19	0.0283	1.69038


AvgSpeed85 = 74.578 +1.1741 Day_Night +0.0177 SfTemp +0.0326 RH - 0.0802 Dewpoint
- 0.1016 AvgWndSpeed - 0.0001 Vis1 +0.4413 wd1
N
4543
Rsq
0.0279
Adj Rsq
0.0264
RMSE
5.2148
Residual
Predicted Value
40
30
20
10
0
-10
-20
-30
70.5
71.0
71.5
72.0
72.5
73.0
73.5
74.0
74.5
75.0
75.5

Sensor 20 Inital Model

The SAS System 14:15 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	5088
Number of Observations Used	4578
Number of Observations with Missing Values	510

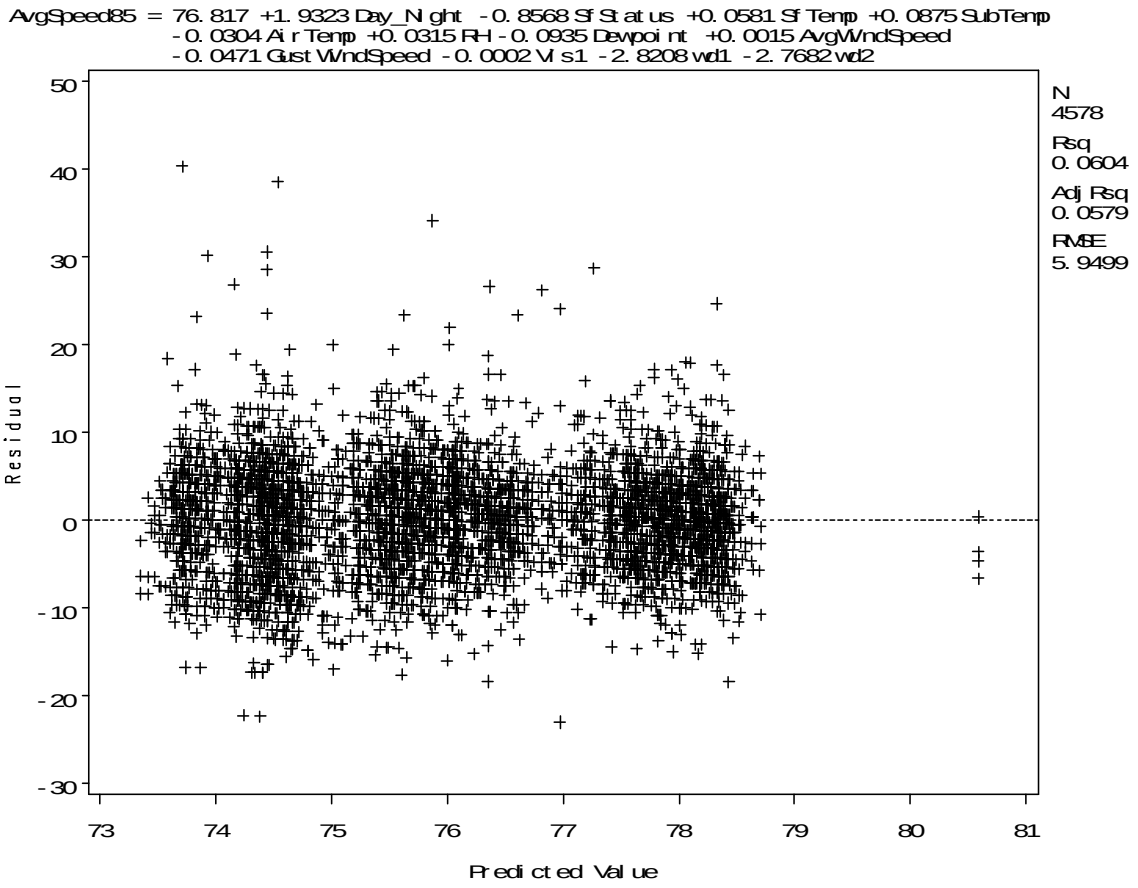
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	12	10387	865.56587	24.45	<.0001
Error	4565	161606	35.40119		
Corrected Total	4577	171993			

Root MSE	5.94989	R-Square	0.0604
Dependent Mean	76.05679	Adj R-Sq	0.0579
Coeff Var	7.82296		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	76.81725	6.57281	11.69	<.0001	0
Day_Night	Day_Night	1	1.93234	0.31710	6.09	<.0001	3.25014
SfStatus	SfStatus	1	-0.85678	2.16225	-0.40	0.6919	1.05469
SfTemp	SfTemp	1	0.05808	0.01714	3.39	0.0007	6.45967
SubTemp	SubTemp	1	0.08750	0.09986	0.88	0.3810	3.29038
AirTemp	AirTemp	1	-0.03041	0.02798	-1.09	0.2771	7.54744
RH	RH	1	0.03152	0.00947	3.33	0.0009	3.32331
Dewpoint	Dewpoint	1	-0.09345	0.02045	-4.57	<.0001	4.43978
AvgWindSpeed	AvgWindSpeed	1	0.00150	0.05779	0.03	0.9793	10.82411
GustWindSpeed	GustWindSpeed	1	-0.04712	0.04661	-1.01	0.3121	11.30562
Vis1	Vis1	1	-0.00015080	0.00004378	-3.44	0.0006	2.59999
wd1		1	-2.82078	2.13999	-1.32	0.1875	148.03748
wd2		1	-2.76822	2.13988	-1.29	0.1959	148.03137


AvgSpeed85 = 76.817 +1.9323 Day_Night -0.8568 SfStatus +0.0581 SfTemp +0.0875 SubTemp
-0.0304 AirTemp +0.0315 RH -0.0935 Dewpoint +0.0015 AvgWindSpeed
-0.0471 GustWindSpeed -0.0002 Vis1 -2.8208 wd1 -2.7682 wd2
N
4578
Rsq
0.0604
Adj Rsq
0.0579
RMSE
5.9499
Residual
Predicted Value
50
40
30
20
10
0
-10
-20
-30
73
74
75
76
77
78
79
80
81

Sensor 20 Final Model

The SAS System 14:15 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	5088
Number of Observations Used	4578
Number of Observations with Missing Values	510

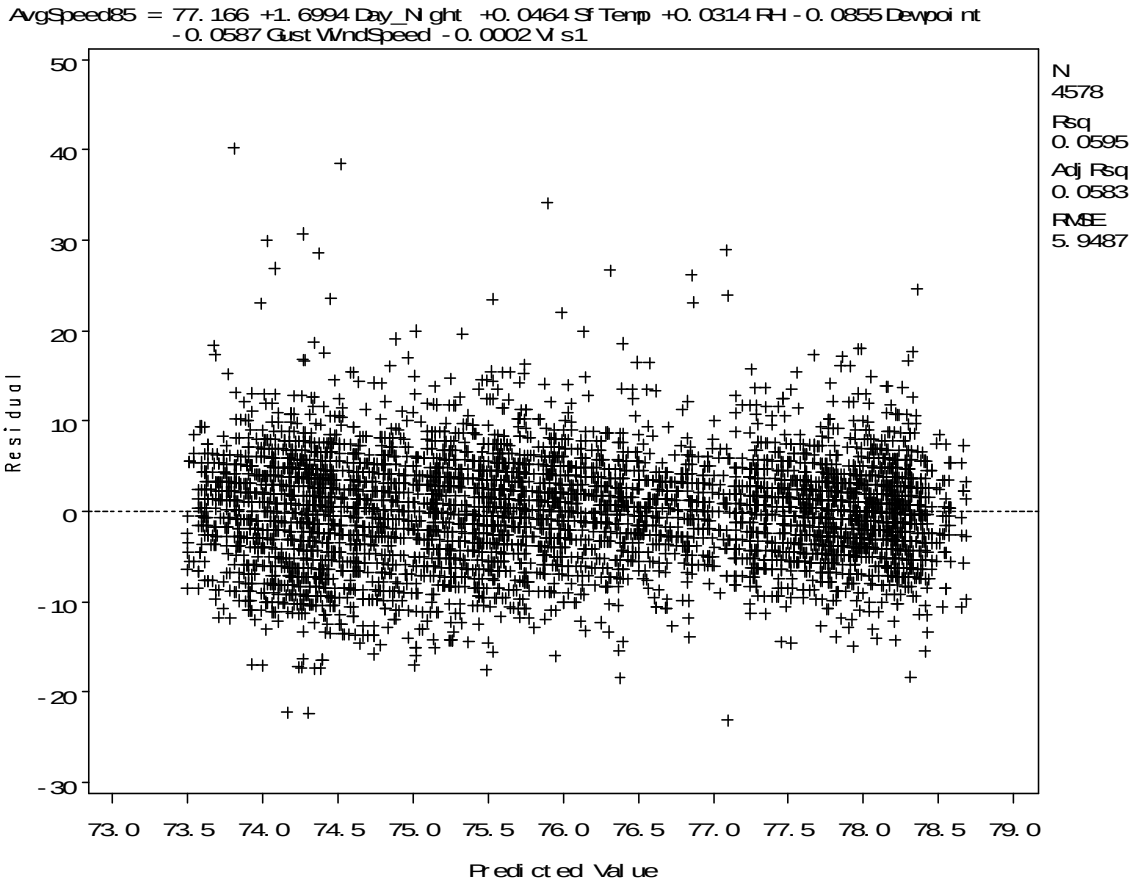
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	10240	1706.64418	48.23	<.0001
Error	4571	161753	35.38687		
Corrected Total	4577	171993			

Root MSE	5.94869	R-Square	0.0595
Dependent Mean	76.05679	Adj R-Sq	0.0583
Coeff Var	7.82137		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	77.16605	1.18409	65.17	<.0001	0
Day_Night	Day_Night	1	1.69938	0.24638	6.90	<.0001	1.96286
SfTemp	SfTemp	1	0.04636	0.01024	4.53	<.0001	2.30422
RH	RH	1	0.03139	0.00851	3.69	0.0002	2.67896
Dewpoint	Dewpoint	1	-0.08551	0.01863	-4.59	<.0001	3.68611
GustWindSpeed	GustWindSpeed	1	-0.05868	0.01611	-3.64	0.0003	1.35042
Vis1	Vis1	1	-0.00016036	0.00003803	-4.22	<.0001	1.96280


AvgSpeed85 = 77.166 +1.6994 Day_Night +0.0464 Sf Temp +0.0314 RH - 0.0855 Dewpoint
- 0.0587 Gust WindSpeed - 0.0002 Vis1
N
4578
Rsq
0.0595
Adj Rsq
0.0583
RMSE
5.9487
Residual
50
40
30
20
10
0
-10
-20
-30
73.0
73.5
74.0
74.5
75.0
75.5
76.0
76.5
77.0
77.5
78.0
78.5
79.0
Predicted Value

Sensor 20 Minus Outliers Initial Model

The SAS System 14:19 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	5088
Number of Observations Used	4578
Number of Observations with Missing Values	510

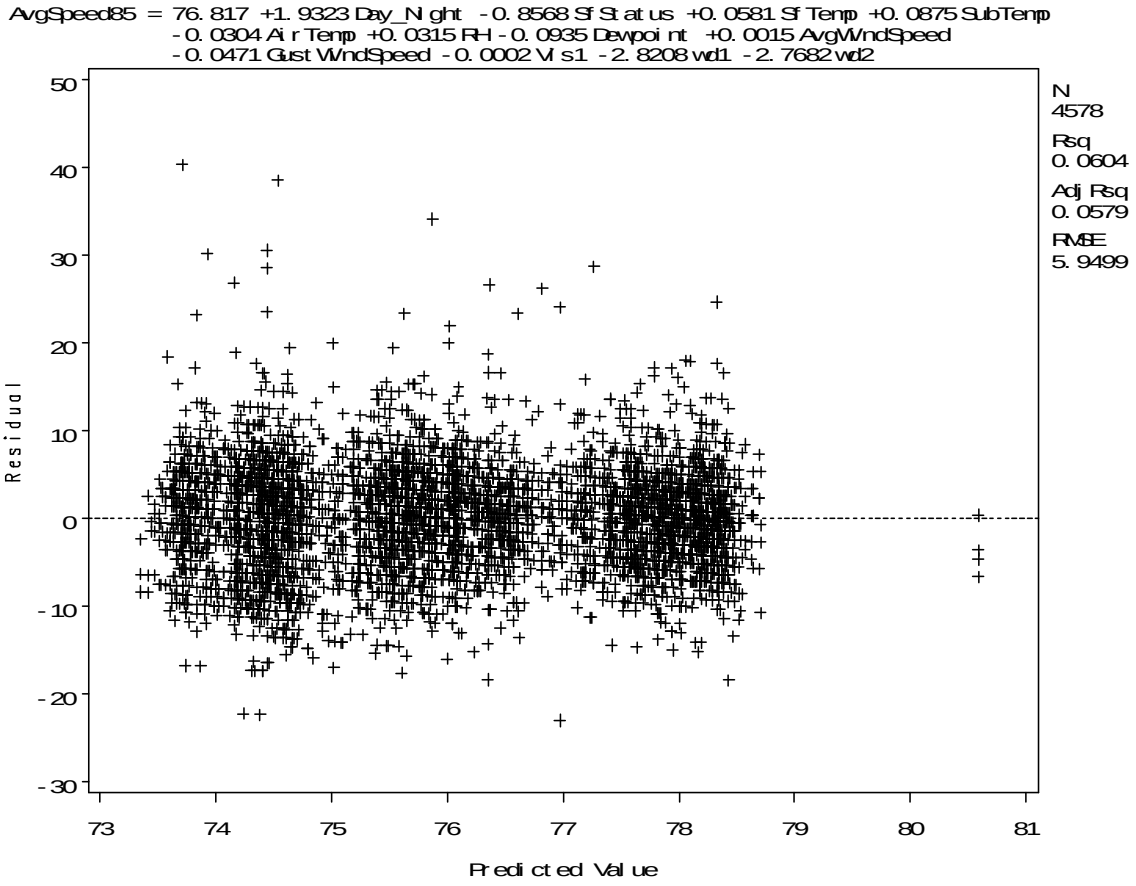
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	12	10387	865.56587	24.45	<.0001
Error	4565	161606	35.40119		
Corrected Total	4577	171993			

Root MSE	5.94989	R-Square	0.0604
Dependent Mean	76.05679	Adj R-Sq	0.0579
Coeff Var	7.82296		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	76.81725	6.57281	11.69	<.0001	0
Day_Night	Day_Night	1	1.93234	0.31710	6.09	<.0001	3.25014
SfStatus	SfStatus	1	-0.85678	2.16225	-0.40	0.6919	1.05469
SfTemp	SfTemp	1	0.05808	0.01714	3.39	0.0007	6.45967
SubTemp	SubTemp	1	0.08750	0.09986	0.88	0.3810	3.29038
AirTemp	AirTemp	1	-0.03041	0.02798	-1.09	0.2771	7.54744
RH	RH	1	0.03152	0.00947	3.33	0.0009	3.32331
Dewpoint	Dewpoint	1	-0.09345	0.02045	-4.57	<.0001	4.43978
AvgWindSpeed	AvgWindSpeed	1	0.00150	0.05779	0.03	0.9793	10.82411
GustWindSpeed	GustWindSpeed	1	-0.04712	0.04661	-1.01	0.3121	11.30562
Vis1	Vis1	1	-0.00015080	0.00004378	-3.44	0.0006	2.59999
wd1		1	-2.82078	2.13999	-1.32	0.1875	148.03748
wd2		1	-2.76822	2.13988	-1.29	0.1959	148.03137


AvgSpeed85 = 76.817 +1.9323 Day_Night -0.8568 SfStatus +0.0581 SfTemp +0.0875 SubTemp
-0.0304 AirTemp +0.0315 RH -0.0935 Dewpoint +0.0015 AvgWndSpeed
-0.0471 GustWndSpeed -0.0002 Vis1 -2.8208 wd1 -2.7682 wd2
N
4578
Rsq
0.0604
Adj Rsq
0.0579
RMSE
5.9499
Residual
Predicted Value

Sensor 20 Minus Outliers Final Model

The SAS System 14:19 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	5088
Number of Observations Used	4578
Number of Observations with Missing Values	510

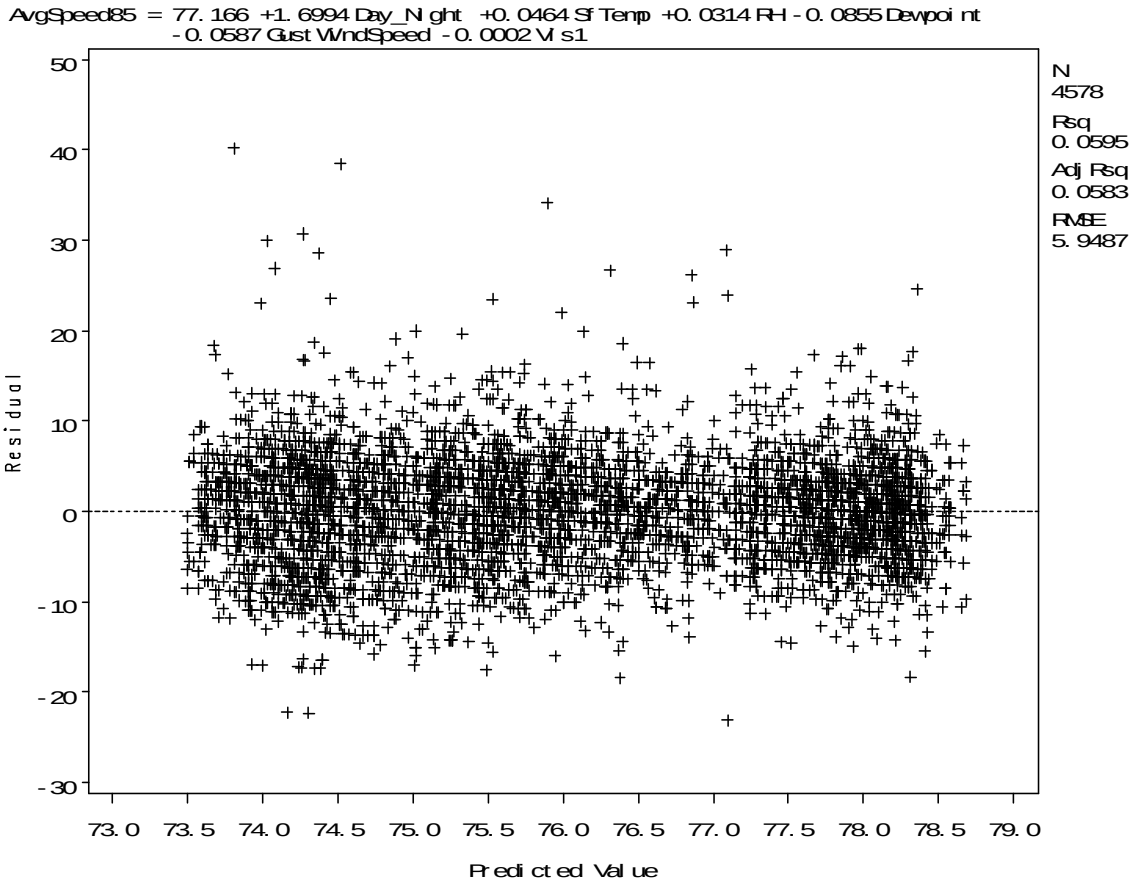
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	10240	1706.64418	48.23	<.0001
Error	4571	161753	35.38687		
Corrected Total	4577	171993			

Root MSE	5.94869	R-Square	0.0595
Dependent Mean	76.05679	Adj R-Sq	0.0583
Coeff Var	7.82137		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	77.16605	1.18409	65.17	<.0001	0
Day_Night	Day_Night	1	1.69938	0.24638	6.90	<.0001	1.96286
SfTemp	SfTemp	1	0.04636	0.01024	4.53	<.0001	2.30422
RH	RH	1	0.03139	0.00851	3.69	0.0002	2.67896
Dewpoint	Dewpoint	1	-0.08551	0.01863	-4.59	<.0001	3.68611
GustWindSpeed	GustWindSpeed	1	-0.05868	0.01611	-3.64	0.0003	1.35042
Vis1	Vis1	1	-0.00016036	0.00003803	-4.22	<.0001	1.96280


AvgSpeed85 = 77.166 +1.6994 Day_Night +0.0464 Sf Temp +0.0314 RH - 0.0855 Dewpoint
- 0.0587 Gust WindSpeed - 0.0002 Vis1
N
4578
Rsq
0.0595
Adj Rsq
0.0583
RMSE
5.9487
Residual
Predicted Value
50
40
30
20
10
0
-10
-20
-30
73.0
73.5
74.0
74.5
75.0
75.5
76.0
76.5
77.0
77.5
78.0
78.5
79.0

Sensor 21 Initial Model

The SAS System 14:22 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	3720
Number of Observations Used	3151
Number of Observations with Missing Values	569

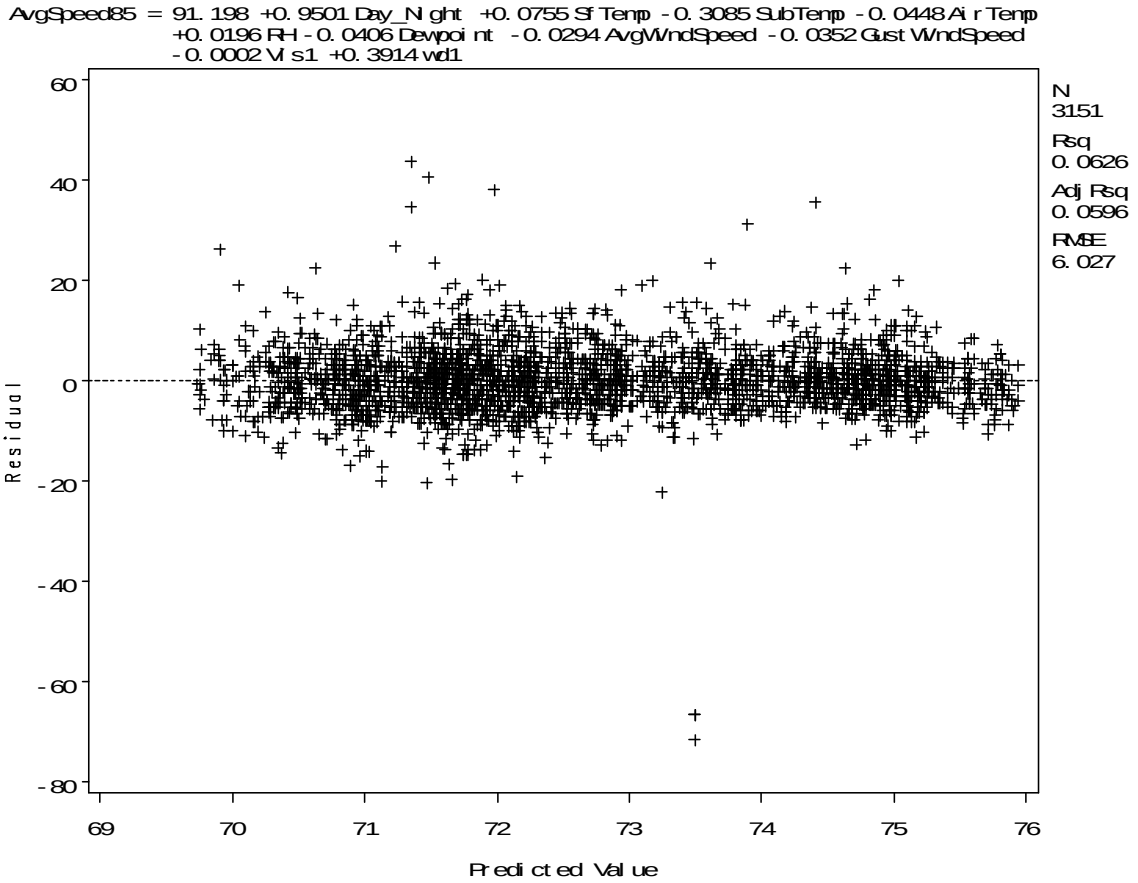
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	10	7617.39261	761.73926	20.97	<.0001
Error	3140	114060	36.32472		
Corrected Total	3150	121677			

Root MSE	6.02700	R-Square	0.0626
Dependent Mean	72.76706	Adj R-Sq	0.0596
Coeff Var	8.28259		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	91.19810	7.74734	11.77	<.0001	0
Day_Night	Day_Night	1	0.95013	0.31952	2.97	0.0030	2.18780
SfTemp	SfTemp	1	0.07550	0.01168	6.47	<.0001	2.03567
SubTemp	SubTemp	1	-0.30845	0.11575	-2.66	0.0077	2.88421
AirTemp	AirTemp	1	-0.04476	0.02586	-1.73	0.0836	3.40856
RH	RH	1	0.01956	0.01124	1.74	0.0819	2.75811
Dewpoint	Dewpoint	1	-0.04058	0.02922	-1.39	0.1650	6.15933
AvgWindSpeed	AvgWindSpeed	1	-0.02944	0.07055	-0.42	0.6765	8.35787
GustWindSpeed	GustWindSpeed	1	-0.03518	0.05911	-0.60	0.5518	9.12726
Vis1	Vis1	1	-0.00020346	0.00005992	-3.40	0.0007	4.00013
wd1		1	0.39136	0.25805	1.52	0.1295	1.42324


AvgSpeed85 = 91.198 +0.9501 Day_Night +0.0755 SfTemp -0.3085 SubTemp -0.0448 AirTemp
+0.0196 RH -0.0406 Dewpoint -0.0294 AvgWindSpeed -0.0352 GustWindSpeed
-0.0002 Vis1 +0.3914 wd1
N
3151
Rsq
0.0626
Adj Rsq
0.0596
RMSE
6.027
Residual
Predicted Value
60
40
20
0
-20
-40
-60
-80
69
70
71
72
73
74
75
76

Sensor 21 Final Model

The SAS System 14:22 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	3720
Number of Observations Used	3151
Number of Observations with Missing Values	569

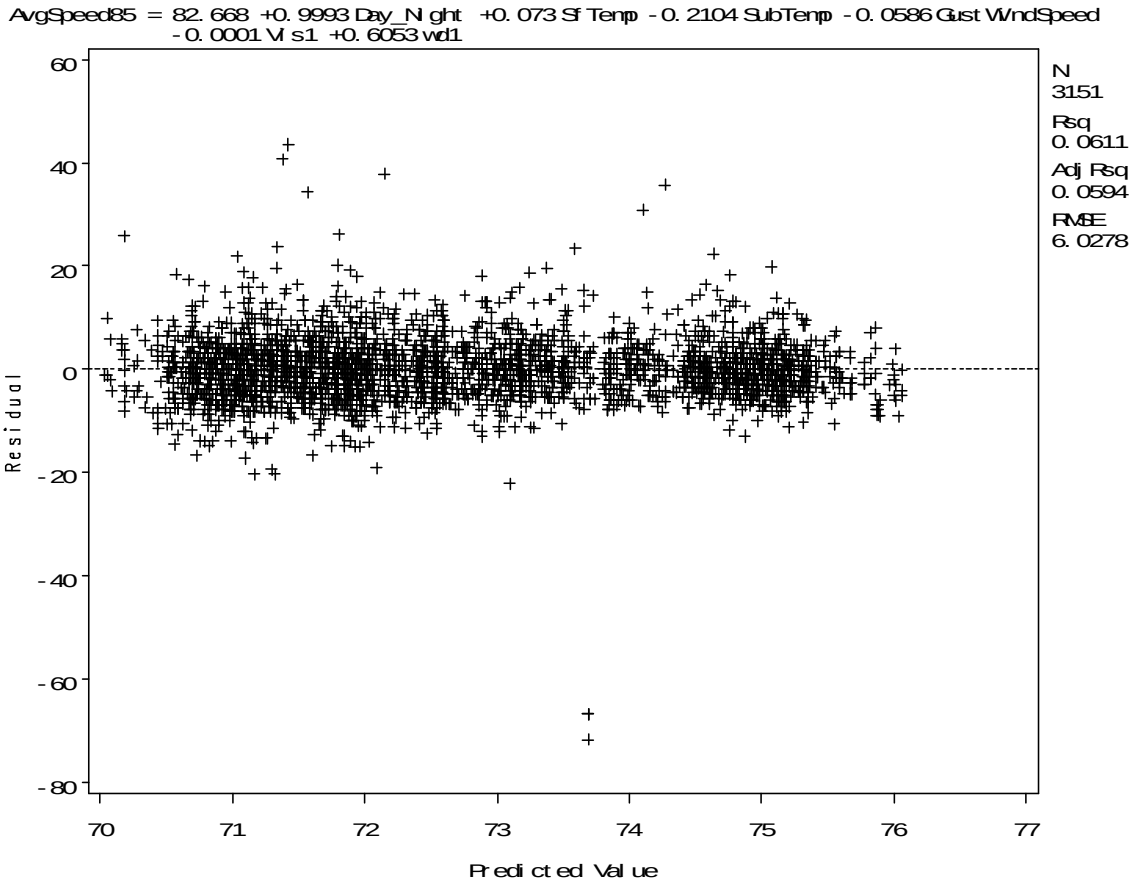
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	7439.93089	1239.98848	34.13	<.0001
Error	3144	114237	36.33495		
Corrected Total	3150	121677			

Root MSE	6.02785	R-Square	0.0611
Dependent Mean	72.76706	Adj R-Sq	0.0594
Coeff Var	8.28376		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	82.66823	5.81475	14.22	<.0001	0
Day_Night	Day_Night	1	0.99930	0.29160	3.43	0.0006	1.82168
SfTemp	SfTemp	1	0.07296	0.01104	6.61	<.0001	1.81953
SubTemp	SubTemp	1	-0.21040	0.09905	-2.12	0.0337	2.11117
GustWindSpeed	GustWindSpeed	1	-0.05860	0.02471	-2.37	0.0178	1.59404
Vis1	Vis1	1	-0.00014028	0.00003523	-3.98	<.0001	1.38289
wd1		1	0.60533	0.22648	2.67	0.0076	1.09593


AvgSpeed85 = 82.668 +0.9993 Day_Night +0.073 SfTemp -0.2104 SubTemp -0.0586 GustWndSpeed
-0.0001 Vis1 +0.6053 wd1
N
3151
Rsq
0.0611
Adj Rsq
0.0594
RMSE
6.0278
Residual
Predicted Value
60
40
20
0
-20
-40
-60
-80
70
71
72
73
74
75
76
77

Sensor 21 Minus Outliers Initial Model

The SAS System 14:25 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	3720
Number of Observations Used	3151
Number of Observations with Missing Values	569

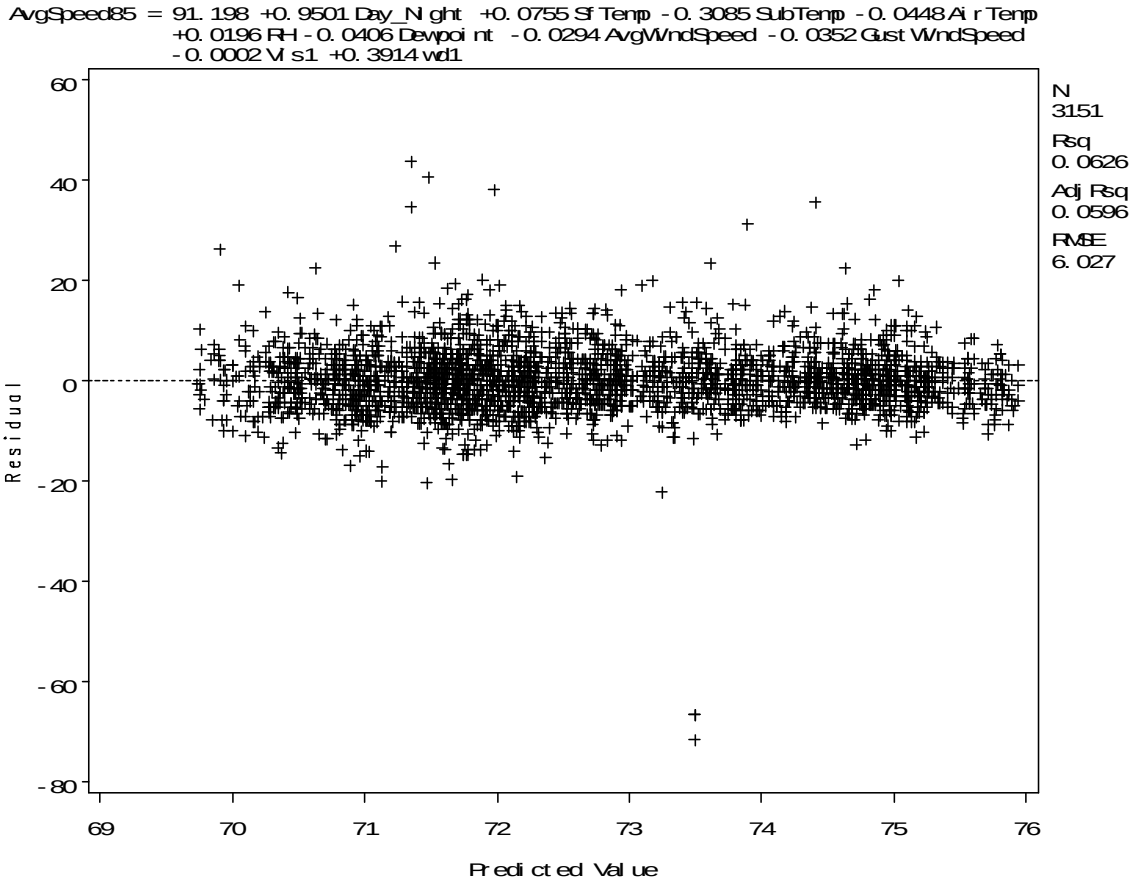
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	10	7617.39261	761.73926	20.97	<.0001
Error	3140	114060	36.32472		
Corrected Total	3150	121677			

Root MSE	6.02700	R-Square	0.0626
Dependent Mean	72.76706	Adj R-Sq	0.0596
Coeff Var	8.28259		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	91.19810	7.74734	11.77	<.0001	0
Day_Night	Day_Night	1	0.95013	0.31952	2.97	0.0030	2.18780
SfTemp	SfTemp	1	0.07550	0.01168	6.47	<.0001	2.03567
SubTemp	SubTemp	1	-0.30845	0.11575	-2.66	0.0077	2.88421
AirTemp	AirTemp	1	-0.04476	0.02586	-1.73	0.0836	3.40856
RH	RH	1	0.01956	0.01124	1.74	0.0819	2.75811
Dewpoint	Dewpoint	1	-0.04058	0.02922	-1.39	0.1650	6.15933
AvgWindSpeed	AvgWindSpeed	1	-0.02944	0.07055	-0.42	0.6765	8.35787
GustWindSpeed	GustWindSpeed	1	-0.03518	0.05911	-0.60	0.5518	9.12726
Vis1	Vis1	1	-0.00020346	0.00005992	-3.40	0.0007	4.00013
wd1		1	0.39136	0.25805	1.52	0.1295	1.42324


AvgSpeed85 = 91.198 +0.9501 Day_Night +0.0755 SfTemp -0.3085 SubTemp -0.0448 AirTemp
+0.0196 RH -0.0406 Dewpoint -0.0294 AvgWndSpeed -0.0352 GustWndSpeed
-0.0002 Vis1 +0.3914 wd1
N
3151
Rsq
0.0626
Adj Rsq
0.0596
RMSE
6.027
Residual
60
40
20
0
-20
-40
-60
-80
69
70
71
72
73
74
75
76
Predicted Value

Sensor 21 Minus Outliers Final Model

The SAS System 14:25 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	3720
Number of Observations Used	3151
Number of Observations with Missing Values	569

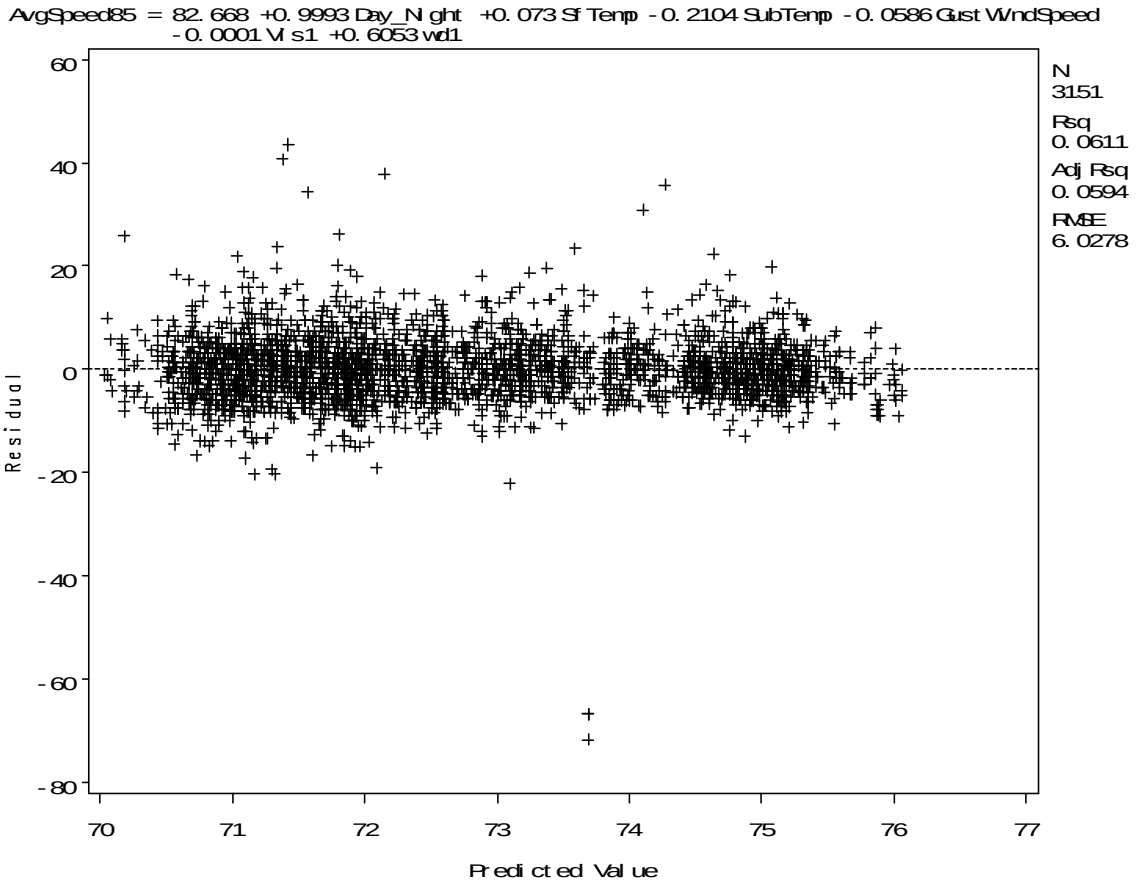
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	7439.93089	1239.98848	34.13	<.0001
Error	3144	114237	36.33495		
Corrected Total	3150	121677			

Root MSE	6.02785	R-Square	0.0611
Dependent Mean	72.76706	Adj R-Sq	0.0594
Coeff Var	8.28376		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	82.66823	5.81475	14.22	<.0001	0
Day_Night	Day_Night	1	0.99930	0.29160	3.43	0.0006	1.82168
SfTemp	SfTemp	1	0.07296	0.01104	6.61	<.0001	1.81953
SubTemp	SubTemp	1	-0.21040	0.09905	-2.12	0.0337	2.11117
GustWindSpeed	GustWindSpeed	1	-0.05860	0.02471	-2.37	0.0178	1.59404
Vis1	Vis1	1	-0.00014028	0.00003523	-3.98	<.0001	1.38289
wd1		1	0.60533	0.22648	2.67	0.0076	1.09593


AvgSpeed85 = 82.668 +0.9993 Day_Night +0.073 SfTemp -0.2104 SubTemp -0.0586 GustWndSpeed
-0.0001 Vis1 +0.6053 wd1
N
3151
Rsq
0.0611
Adj Rsq
0.0594
RMSE
6.0278
Residual
Predicted Value
60
40
20
0
-20
-40
-60
-80
70
71
72
73
74
75
76
77

Sensor 24 Initial Model

The SAS System 14:30 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	4609
Number of Observations Used	1816
Number of Observations with Missing Values	2793

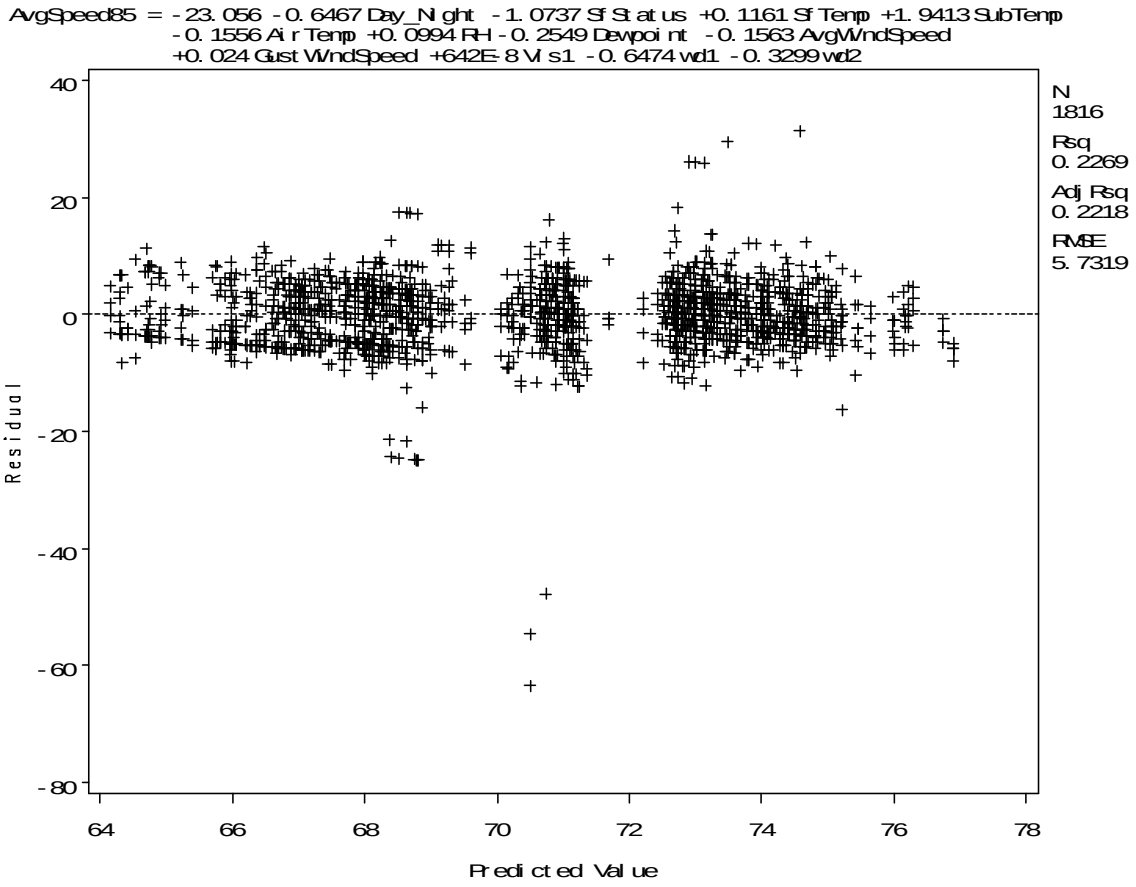
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	12	17386	1448.80917	44.10	<.0001
Error	1803	59236	32.85414		
Corrected Total	1815	76622			

Root MSE	5.73185	R-Square	0.2269
Dependent Mean	70.58866	Adj R-Sq	0.2218
Coeff Var	8.12008		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	-23.05624	8.92887	-2.58	0.0099	0
Day_Night	Day_Night	1	-0.64673	0.55431	-1.17	0.2435	4.23205
SfStatus	SfStatus	1	-1.07371	2.26329	-0.47	0.6353	1.24183
SfTemp	SfTemp	1	0.11614	0.04231	2.75	0.0061	18.46197
SubTemp	SubTemp	1	1.94125	0.16254	11.94	<.0001	4.00517
AirTemp	AirTemp	1	-0.15565	0.05990	-2.60	0.0094	22.77981
RH	RH	1	0.09940	0.02795	3.56	0.0004	13.80325
Dewpoint	Dewpoint	1	-0.25491	0.04637	-5.50	<.0001	13.28018
AvgWindSpeed	AvgWindSpeed	1	-0.15626	0.07932	-1.97	0.0490	10.66057
GustWindSpeed	GustWindSpeed	1	0.02402	0.06282	0.38	0.7022	10.75409
Vis1	Vis1	1	0.00000642	0.00008354	0.08	0.9388	1.86935
wd1		1	-0.64737	0.91753	-0.71	0.4806	11.62985
wd2		1	-0.32987	0.92638	-0.36	0.7218	11.84420


AvgSpeed85 = -23.056 -0.6467 Day_Night -1.0737 SfStatus +0.1161 SfTemp +1.9413 SubTemp
-0.1556 AirTemp +0.0994 RH -0.2549 Dewpoint -0.1563 AvgWndSpeed
+0.024 GustWndSpeed +642E-8 Vis1 -0.6474 wd1 -0.3299 wd2
N
1816
Rsq
0.2269
Adj Rsq
0.2218
RMSE
5.7319
Residual
Predicted Value
40
20
0
-20
-40
-60
-80
64
66
68
70
72
74
76
78

Sensor 24 Final Model

The SAS System 14:30 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	4609
Number of Observations Used	4592
Number of Observations with Missing Values	17

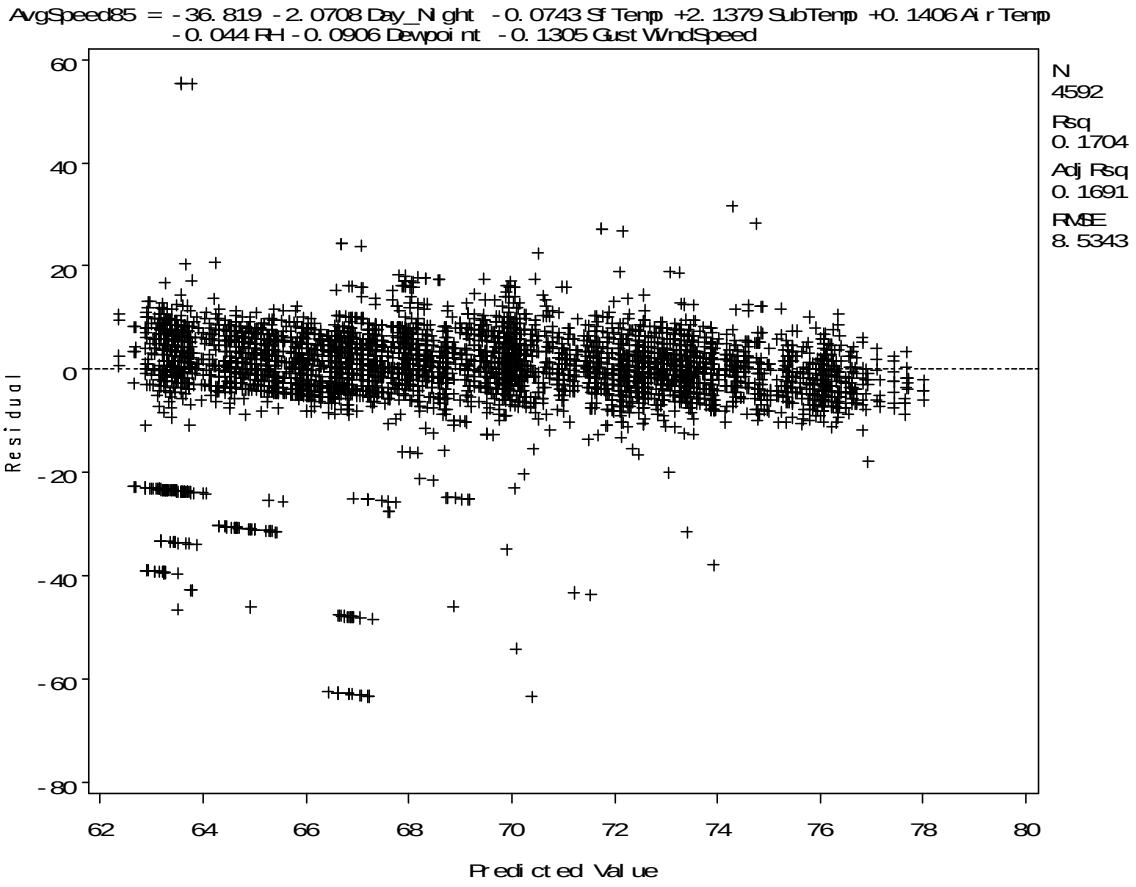
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	68567	9795.30677	134.49	<.0001
Error	4584	333875	72.83489		
Corrected Total	4591	402442			

Root MSE	8.53434	R-Square	0.1704
Dependent Mean	69.28528	Adj R-Sq	0.1691
Coeff Var	12.31768		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	-36.81926	7.88248	-4.67	<.0001	0
Day_Night	Day_Night	1	-2.07076	0.43807	-4.73	<.0001	3.01761
SfTemp	SfTemp	1	-0.07429	0.02842	-2.61	0.0090	8.57819
SubTemp	SubTemp	1	2.13794	0.15301	13.97	<.0001	4.10144
AirTemp	AirTemp	1	0.14060	0.03886	3.62	0.0003	9.21630
RH	RH	1	-0.04402	0.01661	-2.65	0.0081	5.77102
Dewpoint	Dewpoint	1	-0.09063	0.02190	-4.14	<.0001	3.97623
GustWindSpeed	GustWindSpeed	1	-0.13049	0.02539	-5.14	<.0001	2.07815


AvgSpeed85 = -36.819 -2.0708 Day_Night -0.0743 Sf Temp +2.1379 SubTemp +0.1406 Air Temp
-0.044 RH -0.0906 Dewpoint -0.1305 Gust WindSpeed
N
4592
Rsq
0.1704
Adj Rsq
0.1691
RMSE
8.5343
Residual
Predicted Value
60
40
20
0
-20
-40
-60
-80
62
64
66
68
70
72
74
76
78
80

Sensor 24 Minus Outliers Initial Model

The SAS System 14:33 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	4609
Number of Observations Used	1816
Number of Observations with Missing Values	2793

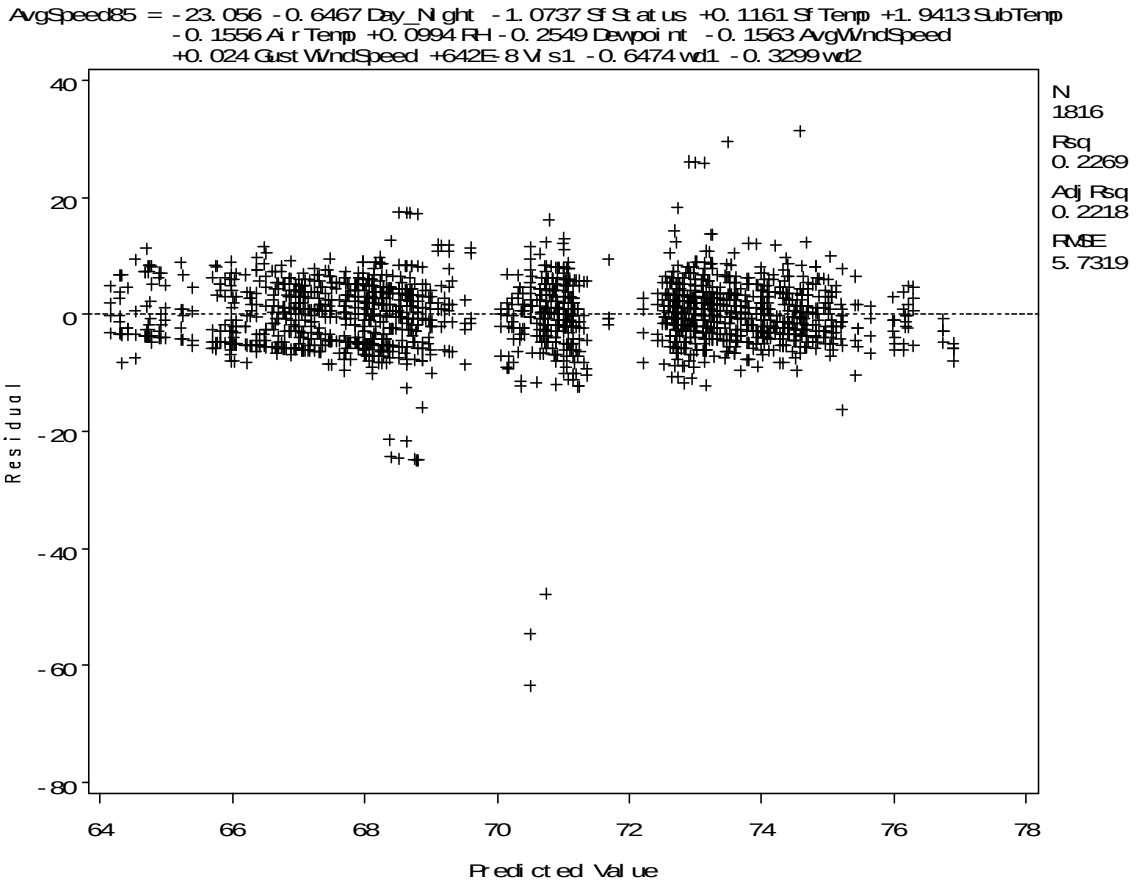
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	12	17386	1448.80917	44.10	<.0001
Error	1803	59236	32.85414		
Corrected Total	1815	76622			

Root MSE	5.73185	R-Square	0.2269
Dependent Mean	70.58866	Adj R-Sq	0.2218
Coeff Var	8.12008		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	-23.05624	8.92887	-2.58	0.0099	0
Day_Night	Day_Night	1	-0.64673	0.55431	-1.17	0.2435	4.23205
SfStatus	SfStatus	1	-1.07371	2.26329	-0.47	0.6353	1.24183
SfTemp	SfTemp	1	0.11614	0.04231	2.75	0.0061	18.46197
SubTemp	SubTemp	1	1.94125	0.16254	11.94	<.0001	4.00517
AirTemp	AirTemp	1	-0.15565	0.05990	-2.60	0.0094	22.77981
RH	RH	1	0.09940	0.02795	3.56	0.0004	13.80325
Dewpoint	Dewpoint	1	-0.25491	0.04637	-5.50	<.0001	13.28018
AvgWindSpeed	AvgWindSpeed	1	-0.15626	0.07932	-1.97	0.0490	10.66057
GustWindSpeed	GustWindSpeed	1	0.02402	0.06282	0.38	0.7022	10.75409
Vis1	Vis1	1	0.00000642	0.00008354	0.08	0.9388	1.86935
wd1		1	-0.64737	0.91753	-0.71	0.4806	11.62985
wd2		1	-0.32987	0.92638	-0.36	0.7218	11.84420


AvgSpeed85 = -23.056 -0.6467 Day_Night -1.0737 SfStatus +0.1161 SfTemp +1.9413 SubTemp
-0.1556 AirTemp +0.0994 RH -0.2549 Dewpoint -0.1563 AvgWndSpeed
+0.024 GustWndSpeed +642E-8 Vis1 -0.6474 wd1 -0.3299 wd2
N
1816
Rsq
0.2269
Adj Rsq
0.2218
RMSE
5.7319
Residual
Predicted Value
40
20
0
-20
-40
-60
-80
64
66
68
70
72
74
76
78

Sensor 24 Minus Outliers Final Model

The SAS System 14:33 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpeed85 AvgSpeed85

Number of Observations Read	4609
Number of Observations Used	4592
Number of Observations with Missing Values	17

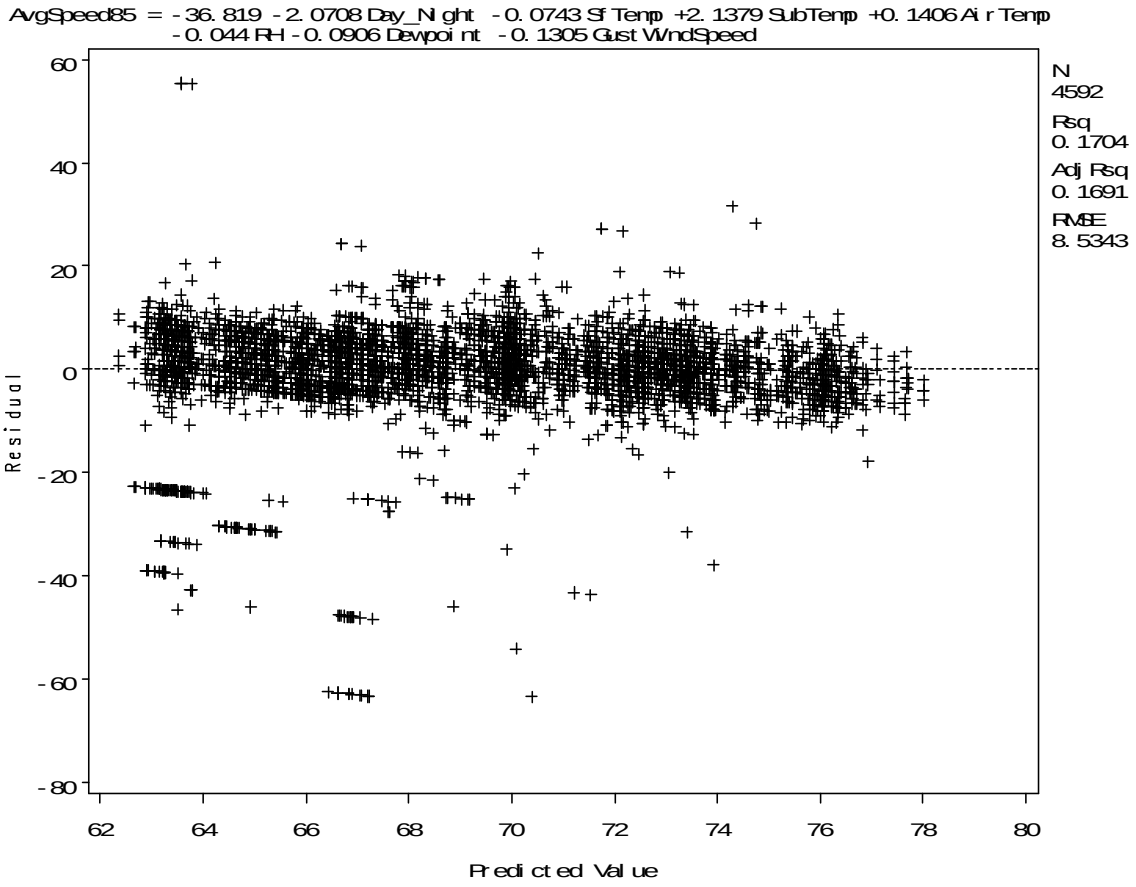
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	68567	9795.30677	134.49	<.0001
Error	4584	333875	72.83489		
Corrected Total	4591	402442			

Root MSE	8.53434	R-Square	0.1704
Dependent Mean	69.28528	Adj R-Sq	0.1691
Coeff Var	12.31768		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	-36.81926	7.88248	-4.67	<.0001	0
Day_Night	Day_Night	1	-2.07076	0.43807	-4.73	<.0001	3.01761
SfTemp	SfTemp	1	-0.07429	0.02842	-2.61	0.0090	8.57819
SubTemp	SubTemp	1	2.13794	0.15301	13.97	<.0001	4.10144
AirTemp	AirTemp	1	0.14060	0.03886	3.62	0.0003	9.21630
RH	RH	1	-0.04402	0.01661	-2.65	0.0081	5.77102
Dewpoint	Dewpoint	1	-0.09063	0.02190	-4.14	<.0001	3.97623
GustWindSpeed	GustWindSpeed	1	-0.13049	0.02539	-5.14	<.0001	2.07815


AvgSpeed85 = -36.819 -2.0708 Day_Night -0.0743 Sf Temp +2.1379 SubTemp +0.1406 Air Temp
-0.044 RH -0.0906 Dewpoint -0.1305 Gust WindSpeed
N
4592
Rsq
0.1704
Adj Rsq
0.1691
RMSE
8.5343
Residual
Predicted Value
60
40
20
0
-20
-40
-60
-80
62
64
66
68
70
72
74
76
78
80

Response to VSL with EB and WB Initial Model

The SAS System 14:37 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpd AvgSpd

Number of Observations Read	20720
Number of Observations Used	17476
Number of Observations with Missing Values	3244

Analysis of Variance

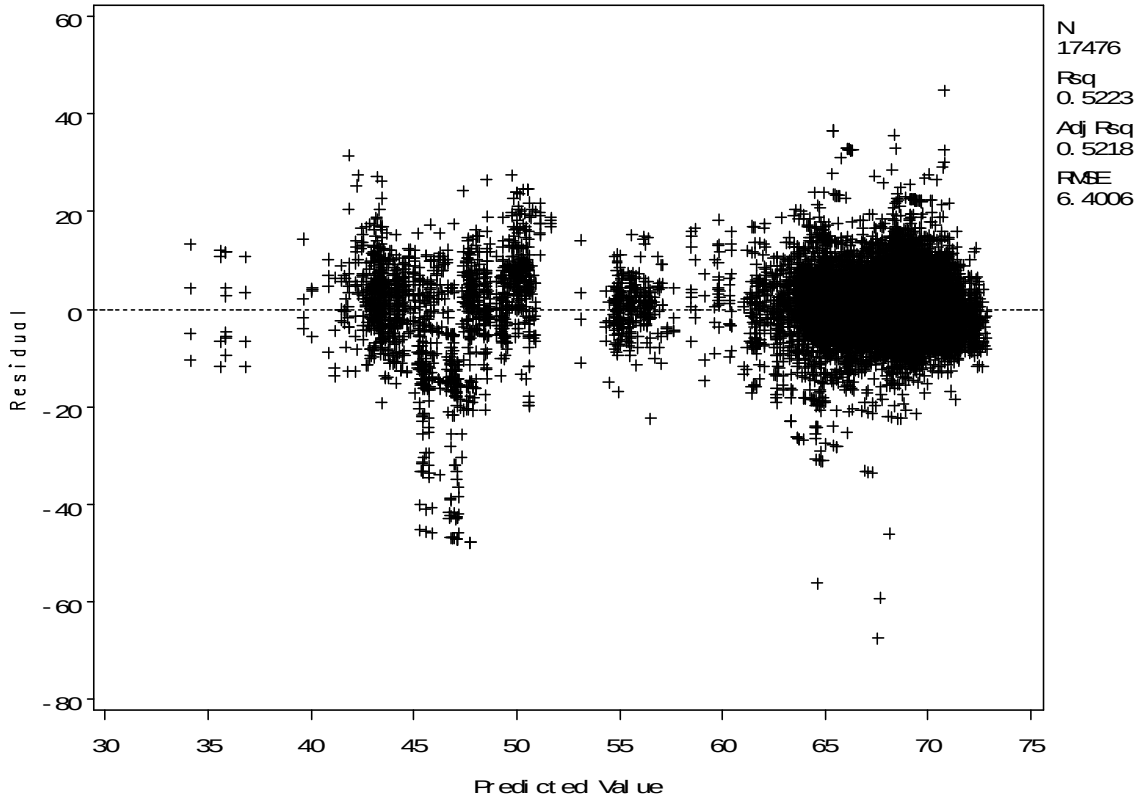
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	20	781956	39098	954.36	<.0001
Error	17455	715086	40.96738		
Corrected Total	17475	1497041			

Root MSE	6.40058	R-Square	0.5223
Dependent Mean	66.36003	Adj R-Sq	0.5218
Coeff Var	9.64523		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	2.85580	1.34593	2.12	0.0339	0
EB	EB	1	1.02673	0.01785	57.51	<.0001	3.03733
WB	WB	1	0.08007	0.01558	5.14	<.0001	4.06546
SfStatus	SfStatus	1	0.05516	0.30375	0.18	0.8559	8.46499
SfTemp	SfTemp	1	0.07432	0.00561	13.24	<.0001	5.89325
SubTemp	SubTemp	1	-0.07377	0.02064	-3.57	0.0004	1.74290
ChemFactor	ChemFactor	1	0.00921	0.01046	0.88	0.3787	2.66014
PrecipRate	PrecipRate	1	-14.11693	1.14892	-12.29	<.0001	1.20374
AirTemp	AirTemp	1	-0.10785	0.01676	-6.44	<.0001	12.05819
RH	RH	1	-0.06098	0.00944	-6.46	<.0001	31.27625
Dewpoint	Dewpoint	1	0.09677	0.01799	5.38	<.0001	14.61963
AvgWindSpeed	AvgWindSpeed	1	-0.07990	0.02092	-3.82	0.0001	16.82027
GustWindSpeed	GustWindSpeed	1	-0.00993	0.01682	-0.59	0.5550	17.02447
Visibility	Visibility	1	0.00005683	0.00001108	5.13	<.0001	3.60369
wd1		1	-1.15573	1.05747	-1.09	0.2744	1.30661
wd2		1	-2.94732	0.65545	-4.50	<.0001	2.80804
wd3		1	-1.13186	0.61117	-1.85	0.0640	3.38938
wd4		1	-0.81479	2.31737	-0.35	0.7251	1.04820
wd5		1	1.82236	1.09167	1.67	0.0951	1.27673
wd6		1	0.85687	0.51236	1.67	0.0945	27.31943
wd7		1	0.18008	0.50871	0.35	0.7233	25.72306

AvgSpd = 2.8558 +1.0267 EB +0.0801 VB +0.0552 SfStatus +0.0743 SfTemp -0.0738 SubTemp
+0.0092 ChemFactor -14.117 PrecipRate -0.1078 AirTemp -0.061 RH +0.0968 Dewpoint
-0.0799 AvgWindSpeed -0.0099 GustWindSpeed +568E-7 Visibility -1.1557 wd1
-2.9473 wd2 -1.1319 wd3 -0.8148 wd4 +1.8224 wd5 +0.8569 wd6 +0.1801 wd7



Response to VSL with EB and WB Final Model

The SAS System 14:37 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpd AvgSpd

Number of Observations Read	20720
Number of Observations Used	17552
Number of Observations with Missing Values	3168

Analysis of Variance

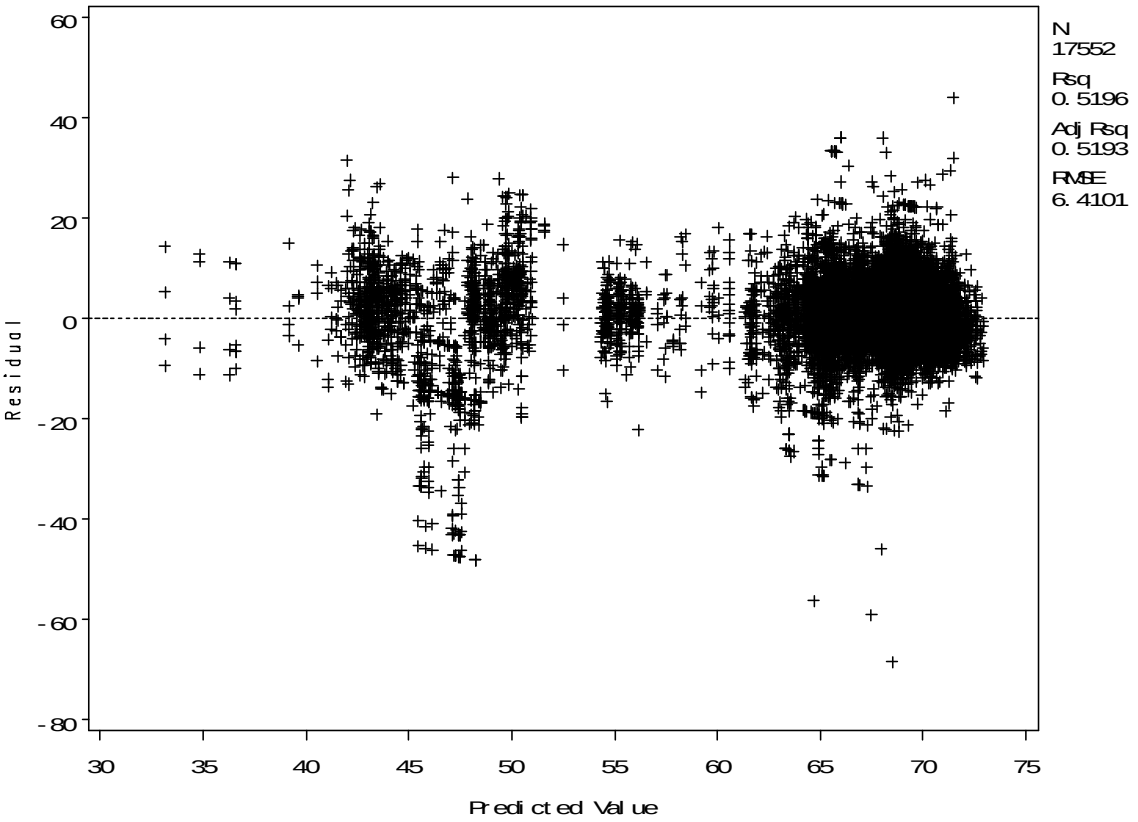
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	779578	70871	1724.80	<.0001
Error	17540	720704	41.08915		
Corrected Total	17551	1500282			

Root MSE	6.41008	R-Square	0.5196
Dependent Mean	66.36823	Adj R-Sq	0.5193
Coeff Var	9.65836		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	-1.30890	0.95470	-1.37	0.1704	0
EB	EB	1	1.02801	0.01739	59.12	<.0001	2.87451
WB	WB	1	0.08864	0.01517	5.85	<.0001	3.94397
SfTemp	SfTemp	1	0.06991	0.00351	19.90	<.0001	2.30658
SubTemp	SubTemp	1	-0.10230	0.01744	-5.87	<.0001	1.27213
PrecipRate	PrecipRate	1	-15.81433	1.12279	-14.08	<.0001	1.14634
RH	RH	1	-0.01130	0.00285	-3.97	<.0001	2.86691
AvgWindSpeed	AvgWindSpeed	1	-0.09483	0.00586	-16.18	<.0001	1.32999
Visibility	Visibility	1	0.00006468	0.00001065	6.07	<.0001	3.46389
wd2		1	-3.41976	0.41216	-8.30	<.0001	1.12312
wd3		1	-1.44322	0.35768	-4.03	<.0001	1.15754
wd6		1	0.78113	0.11119	7.03	<.0001	1.29025

AvgSpd = -1.3089 +1.028 EB3 +0.0886 VB3 +0.0699 SfTemp -0.1023 SubTemp -15.814 PreciipRate
-0.0113 RH -0.0948 AvgWindSpeed +0.0001 Visibility -3.4198 wd2 -1.4432 wd3
+0.7811 wd6



Response to VSL with EB and WB Minus Outliers Initial Model

The SAS System 14:41 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpd AvgSpd

Number of Observations Read	20720
Number of Observations Used	17476
Number of Observations with Missing Values	3244

Analysis of Variance

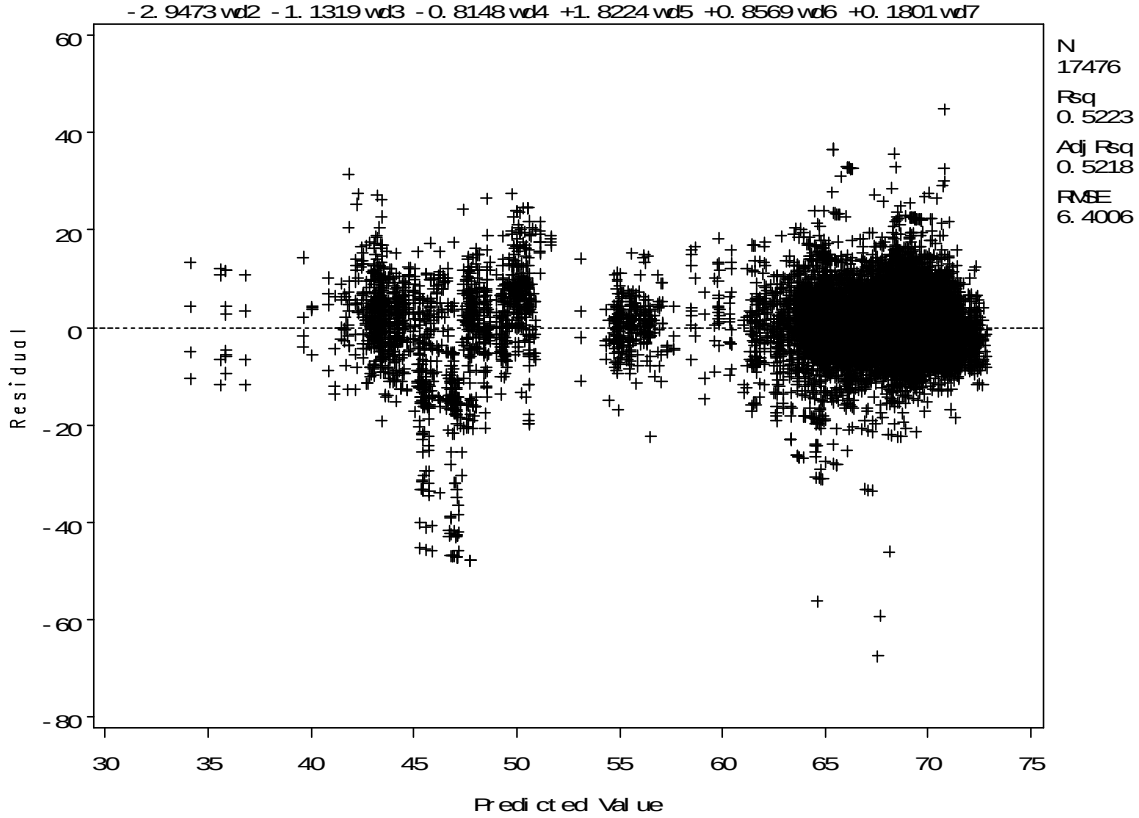
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	20	781956	39098	954.36	<.0001
Error	17455	715086	40.96738		
Corrected Total	17475	1497041			

Root MSE	6.40058	R-Square	0.5223
Dependent Mean	66.36003	Adj R-Sq	0.5218
Coeff Var	9.64523		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	2.85580	1.34593	2.12	0.0339	0
EB	EB	1	1.02673	0.01785	57.51	<.0001	3.03733
WB	WB	1	0.08007	0.01558	5.14	<.0001	4.06546
SfStatus	SfStatus	1	0.05516	0.30375	0.18	0.8559	8.46499
SfTemp	SfTemp	1	0.07432	0.00561	13.24	<.0001	5.89325
SubTemp	SubTemp	1	-0.07377	0.02064	-3.57	0.0004	1.74290
ChemFactor	ChemFactor	1	0.00921	0.01046	0.88	0.3787	2.66014
PrecipRate	PrecipRate	1	-14.11693	1.14892	-12.29	<.0001	1.20374
AirTemp	AirTemp	1	-0.10785	0.01676	-6.44	<.0001	12.05819
RH	RH	1	-0.06098	0.00944	-6.46	<.0001	31.27625
Dewpoint	Dewpoint	1	0.09677	0.01799	5.38	<.0001	14.61963
AvgWindSpeed	AvgWindSpeed	1	-0.07990	0.02092	-3.82	0.0001	16.82027
GustWindSpeed	GustWindSpeed	1	-0.00993	0.01682	-0.59	0.5550	17.02447
Visibility	Visibility	1	0.00005683	0.00001108	5.13	<.0001	3.60369
wd1		1	-1.15573	1.05747	-1.09	0.2744	1.30661
wd2		1	-2.94732	0.65545	-4.50	<.0001	2.80804
wd3		1	-1.13186	0.61117	-1.85	0.0640	3.38938
wd4		1	-0.81479	2.31737	-0.35	0.7251	1.04820
wd5		1	1.82236	1.09167	1.67	0.0951	1.27673
wd6		1	0.85687	0.51236	1.67	0.0945	27.31943
wd7		1	0.18008	0.50871	0.35	0.7233	25.72306

AvgSpd = 2.8558 +1.0267 EB +0.0801 VB +0.0552 SfStatus +0.0743 SfTemp -0.0738 SubTemp
+0.0092 ChenFactor -14.117 PrecipRate -0.1078 AirTemp -0.061 RH +0.0968 Dewpoint
-0.0799 AvgWndSpeed -0.0099 GustWndSpeed +568E-7 Visibility -1.1557 wd1
-2.9473 wd2 -1.1319 wd3 -0.8148 wd4 +1.8224 wd5 +0.8569 wd6 +0.1801 wd7



Response to VSL with EB and WB Minus Outliers Final Model

The SAS System 14:41 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpd AvgSpd

Number of Observations Read	20720
Number of Observations Used	17552
Number of Observations with Missing Values	3168

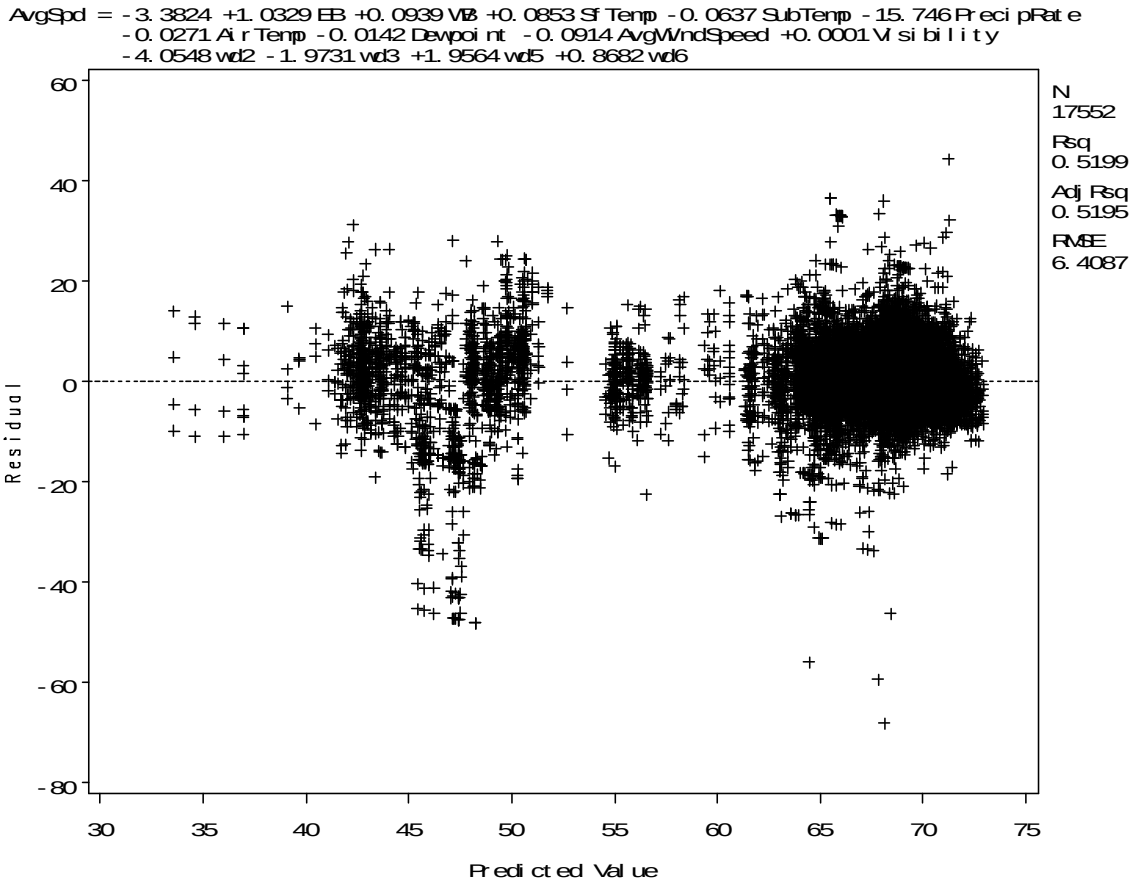
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	13	779971	59998	1460.82	<.0001
Error	17538	720311	41.07143		
Corrected Total	17551	1500282			

Root MSE	6.40870	R-Square	0.5199
Dependent Mean	66.36823	Adj R-Sq	0.5195
Coeff Var	9.65628		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	-3.38242	0.91170	-3.71	0.0002	0
EB	EB	1	1.03288	0.01744	59.23	<.0001	2.89130
WB	WB	1	0.09394	0.01510	6.22	<.0001	3.91275
SfTemp	SfTemp	1	0.08526	0.00383	22.26	<.0001	2.74444
SubTemp	SubTemp	1	-0.06375	0.01972	-3.23	0.0012	1.62644
PrecipRate	PrecipRate	1	-15.74602	1.12243	-14.03	<.0001	1.14610
AirTemp	AirTemp	1	-0.02705	0.00822	-3.29	0.0010	2.91146
Dewpoint	Dewpoint	1	-0.01416	0.00607	-2.33	0.0196	1.67671
AvgWindSpeed	AvgWindSpeed	1	-0.09140	0.00590	-15.48	<.0001	1.35056
Visibility	Visibility	1	0.00006874	0.00001072	6.41	<.0001	3.51105
wd2		1	-4.05485	0.41917	-9.67	<.0001	1.16217
wd3		1	-1.97314	0.35781	-5.51	<.0001	1.15889
wd5		1	1.95644	0.97223	2.01	0.0442	1.01010
wd6		1	0.86820	0.11005	7.89	<.0001	1.26452


AvgSpd = -3.3824 +1.0329 EB3 +0.0939 VB3 +0.0853 SfTemp -0.0637 SubTemp -15.746 PrecipRate
-0.0271 AirTemp -0.0142 Dewpoint -0.0914 AvgWindSpeed +0.0001 Visibility
-4.0548 wd2 -1.9731 wd3 +1.9564 wd5 +0.8682 wd6
N
17552
Rsq
0.5199
Adj Rsq
0.5195
RMSE
6.4087
Residual
Predicted Value
60
40
20
0
-20
-40
-60
-80
30
35
40
45
50
55
60
65
70
75

Response to VSL with EB Initial Model

The SAS System 14:46 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpd AvgSpd

Number of Observations Read	20720
Number of Observations Used	17476
Number of Observations with Missing Values	3244

Analysis of Variance

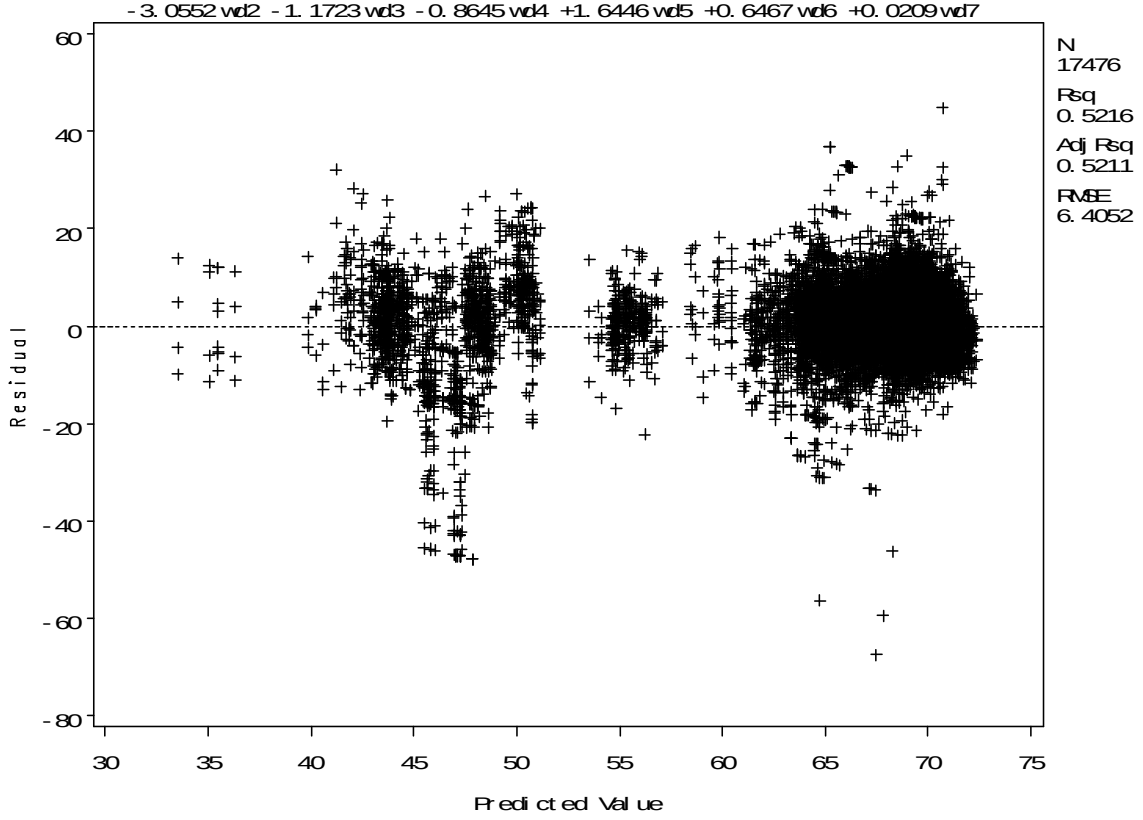
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	19	780873	41099	1001.74	<.0001
Error	17456	716168	41.02706		
Corrected Total	17475	1497041			

Root MSE	6.40524	R-Square	0.5216
Dependent Mean	66.36003	Adj R-Sq	0.5211
Coeff Var	9.65225		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	4.45965	1.31023	3.40	0.0007	0
EB	EB	1	1.09046	0.01286	84.81	<.0001	1.57314
SfStatus	SfStatus	1	0.24909	0.30162	0.83	0.4089	8.33443
SfTemp	SfTemp	1	0.07291	0.00561	13.00	<.0001	5.87927
SubTemp	SubTemp	1	-0.07482	0.02065	-3.62	0.0003	1.74273
ChemFactor	ChemFactor	1	0.01351	0.01044	1.29	0.1956	2.64315
PrecipRate	PrecipRate	1	-14.24780	1.14948	-12.40	<.0001	1.20315
AirTemp	AirTemp	1	-0.11249	0.01674	-6.72	<.0001	12.02312
RH	RH	1	-0.06558	0.00940	-6.97	<.0001	30.99527
Dewpoint	Dewpoint	1	0.10542	0.01792	5.88	<.0001	14.49185
AvgWindSpeed	AvgWindSpeed	1	-0.08659	0.02090	-4.14	<.0001	16.75511
GustWindSpeed	GustWindSpeed	1	-0.00226	0.01676	-0.13	0.8929	16.89048
Visibility	Visibility	1	0.00001628	0.00000779	2.09	0.0365	1.77702
wd1		1	-1.11959	1.05822	-1.06	0.2901	1.30656
wd2		1	-3.05516	0.65560	-4.66	<.0001	2.80516
wd3		1	-1.17226	0.61156	-1.92	0.0553	3.38882
wd4		1	-0.86452	2.31903	-0.37	0.7093	1.04818
wd5		1	1.64458	1.09191	1.51	0.1320	1.27545
wd6		1	0.64672	0.51110	1.27	0.2058	27.14553
wd7		1	0.02088	0.50814	0.04	0.9672	25.62774

AvgSpd = 4.4596 +1.0905 EB +0.2491 SfStatus +0.0729 SfTemp -0.0748 SubTemp
+0.0135 ChemFactor -14.248 PrecipRate -0.1125 AirTemp -0.0656 RH +0.1054 Dewpoint
-0.0866 AvgWindSpeed -0.0023 GustWindSpeed +163E-7 Visibility -1.1196 wd1
-3.0552 wd2 -1.1723 wd3 -0.8645 wd4 +1.6446 wd5 +0.6467 wd6 +0.0209 wd7



Response to VSL with EB Final Model

The SAS System 14:46 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpd AvgSpd

Number of Observations Read	20720
Number of Observations Used	17552
Number of Observations with Missing Values	3168

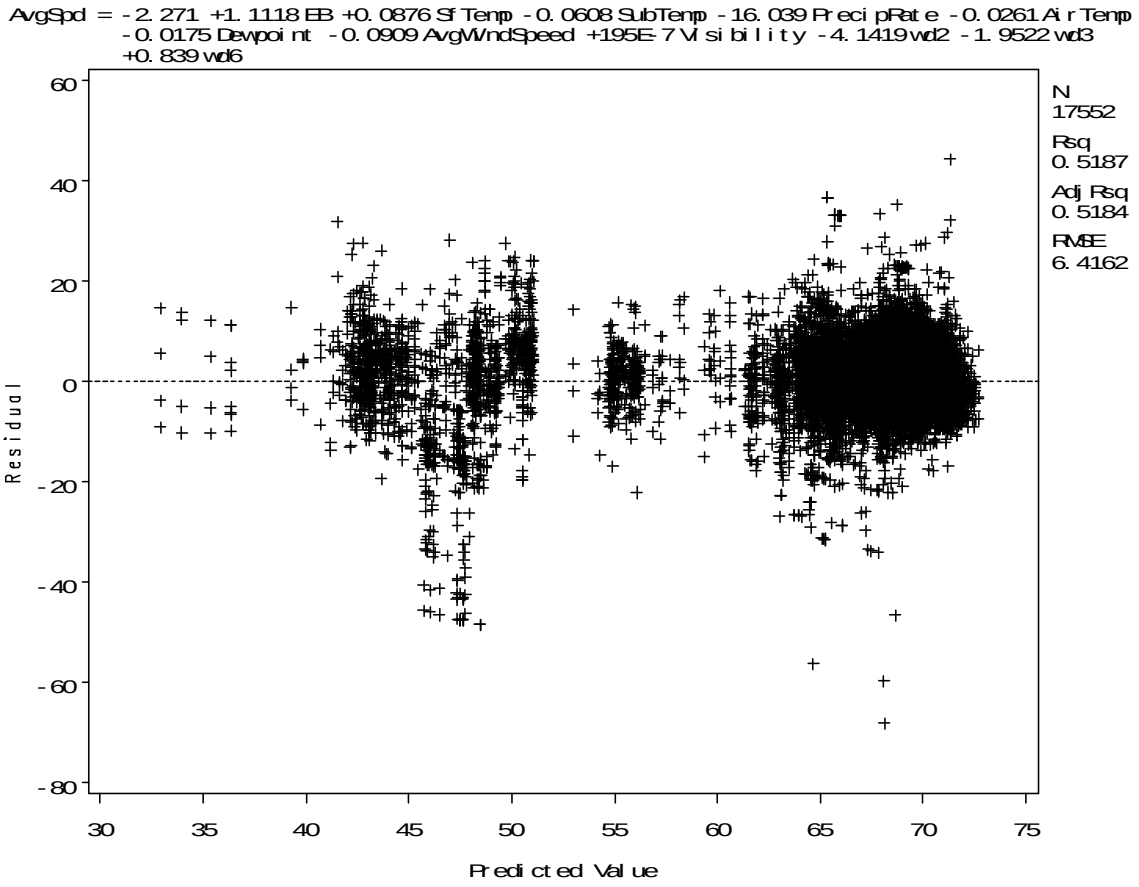
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	778203	70746	1718.48	<.0001
Error	17540	722079	41.16756		
Corrected Total	17551	1500282			

Root MSE	6.41619	R-Square	0.5187
Dependent Mean	66.36823	Adj R-Sq	0.5184
Coeff Var	9.66757		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	-2.27100	0.89408	-2.54	0.0111	0
EB	EB	1	1.11177	0.01202	92.46	<.0001	1.37175
SfTemp	SfTemp	1	0.08763	0.00382	22.96	<.0001	2.71776
SubTemp	SubTemp	1	-0.06075	0.01972	-3.08	0.0021	1.62336
PrecipRate	PrecipRate	1	-16.03862	1.12285	-14.28	<.0001	1.14428
AirTemp	AirTemp	1	-0.02607	0.00821	-3.17	0.0015	2.90015
Dewpoint	Dewpoint	1	-0.01751	0.00605	-2.89	0.0038	1.66477
AvgWindSpeed	AvgWindSpeed	1	-0.09094	0.00591	-15.39	<.0001	1.35032
Visibility	Visibility	1	0.00001955	0.00000729	2.68	0.0074	1.62044
wd2		1	-4.14186	0.41933	-9.88	<.0001	1.16033
wd3		1	-1.95217	0.35799	-5.45	<.0001	1.15738
wd6		1	0.83899	0.10987	7.64	<.0001	1.25746


AvgSpd = -2.271 +1.1118 EB +0.0876 SfTemp -0.0608 SubTemp -16.039 PrecipRate -0.0261 AirTemp
-0.0175 Dewpoint -0.0909 AvgWindSpeed +195E-7 Visibility -4.1419 wd2 -1.9522 wd3
+0.839 wd6
N
17552
Rsq
0.5187
Adj Rsq
0.5184
RMSE
6.4162
Residual
Predicted Value
60
40
20
0
-20
-40
-60
-80
30
35
40
45
50
55
60
65
70
75

Response to VSL with EB Minus Outliers Initial Model

The SAS System 14:50 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpd AvgSpd

Number of Observations Read	20720
Number of Observations Used	17476
Number of Observations with Missing Values	3244

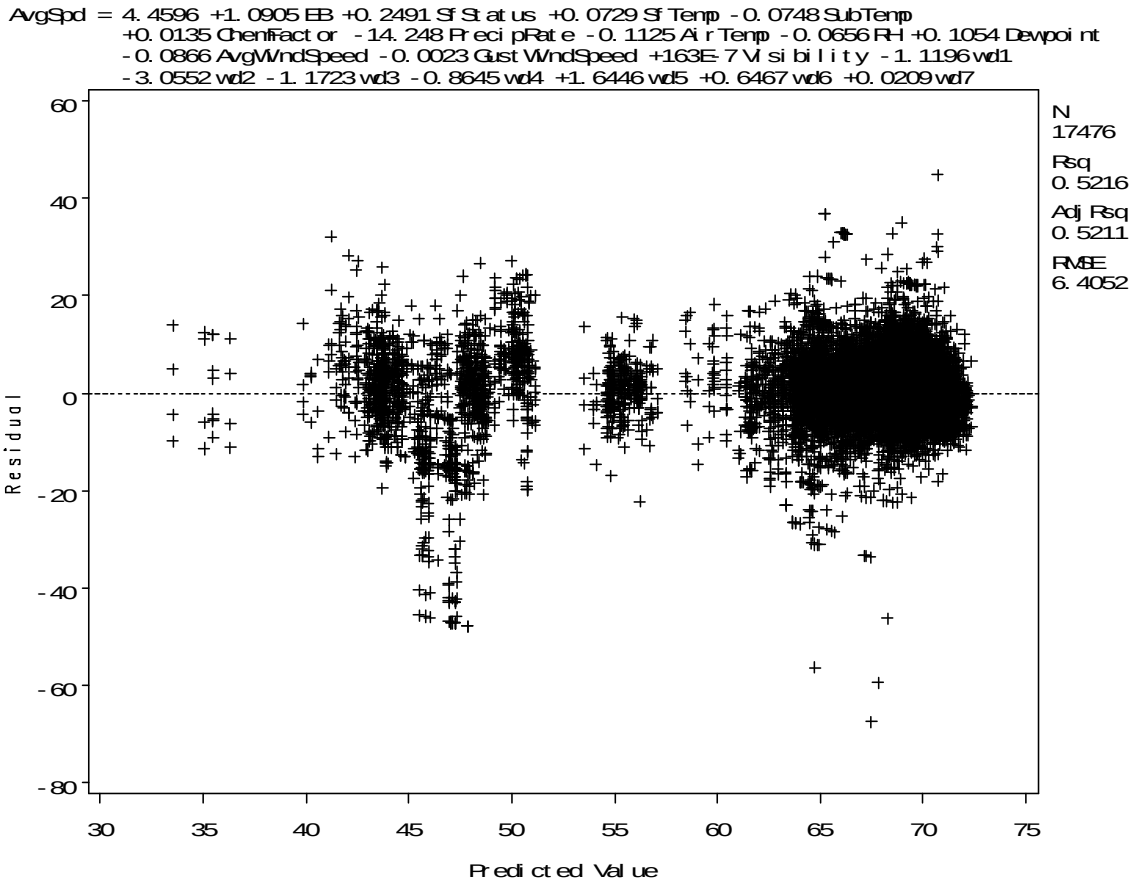
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	19	780873	41099	1001.74	<.0001
Error	17456	716168	41.02706		
Corrected Total	17475	1497041			

Root MSE	6.40524	R-Square	0.5216
Dependent Mean	66.36003	Adj R-Sq	0.5211
Coeff Var	9.65225		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	4.45965	1.31023	3.40	0.0007	0
EB	EB	1	1.09046	0.01286	84.81	<.0001	1.57314
SfStatus	SfStatus	1	0.24909	0.30162	0.83	0.4089	8.33443
SfTemp	SfTemp	1	0.07291	0.00561	13.00	<.0001	5.87927
SubTemp	SubTemp	1	-0.07482	0.02065	-3.62	0.0003	1.74273
ChemFactor	ChemFactor	1	0.01351	0.01044	1.29	0.1956	2.64315
PrecipRate	PrecipRate	1	-14.24780	1.14948	-12.40	<.0001	1.20315
AirTemp	AirTemp	1	-0.11249	0.01674	-6.72	<.0001	12.02312
RH	RH	1	-0.06558	0.00940	-6.97	<.0001	30.99527
Dewpoint	Dewpoint	1	0.10542	0.01792	5.88	<.0001	14.49185
AvgWindSpeed	AvgWindSpeed	1	-0.08659	0.02090	-4.14	<.0001	16.75511
GustWindSpeed	GustWindSpeed	1	-0.00226	0.01676	-0.13	0.8929	16.89048
Visibility	Visibility	1	0.00001628	0.00000779	2.09	0.0365	1.77702
wd1		1	-1.11959	1.05822	-1.06	0.2901	1.30656
wd2		1	-3.05516	0.65560	-4.66	<.0001	2.80516
wd3		1	-1.17226	0.61156	-1.92	0.0553	3.38882
wd4		1	-0.86452	2.31903	-0.37	0.7093	1.04818
wd5		1	1.64458	1.09191	1.51	0.1320	1.27545
wd6		1	0.64672	0.51110	1.27	0.2058	27.14553
wd7		1	0.02088	0.50814	0.04	0.9672	25.62774


AvgSpd = 4.4596 +1.0905 EB +0.2491 SfStatus +0.0729 SfTemp -0.0748 SubTemp
+0.0135 ChemFractor -14.248 PrecipRate -0.1125 AirTemp -0.0656 RH +0.1054 Dewpoint
-0.0866 AvgWindSpeed -0.0023 GustWindSpeed +163E-7 Visibility -1.1196 wd1
-3.0552 wd2 -1.1723 wd3 -0.8645 wd4 +1.6446 wd5 +0.6467 wd6 +0.0209 wd7
N
17476
Rsq
0.5216
Adj Rsq
0.5211
RMSE
6.4052
Residual
Predicted Value
60
40
20
0
-20
-40
-60
-80
30
35
40
45
50
55
60
65
70
75

Response to VSL with EB Minus Outliers Final Model

The SAS System 14:50 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpd AvgSpd

Number of Observations Read	20720
Number of Observations Used	17552
Number of Observations with Missing Values	3168

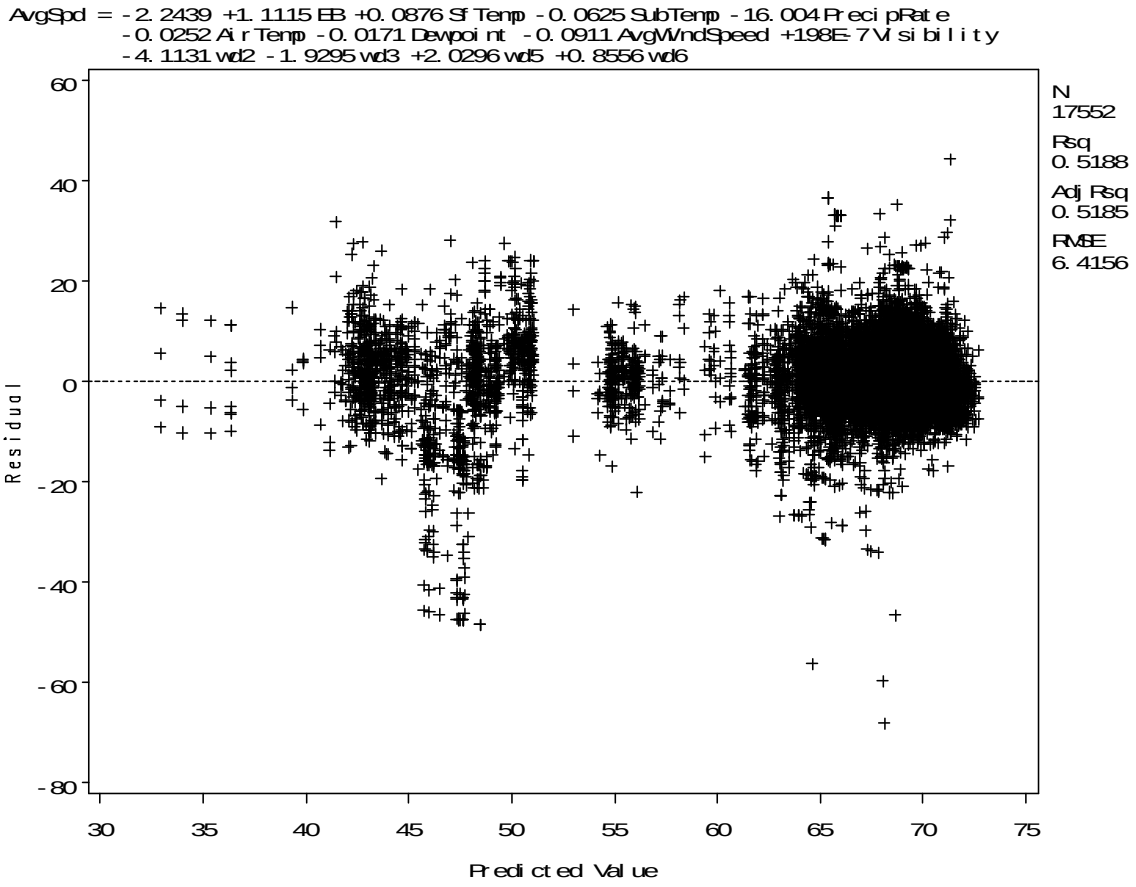
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	12	778382	64865	1575.94	<.0001
Error	17539	721900	41.15970		
Corrected Total	17551	1500282			

Root MSE	6.41558	R-Square	0.5188
Dependent Mean	66.36823	Adj R-Sq	0.5185
Coeff Var	9.66665		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	-2.24386	0.89409	-2.51	0.0121	0
EB	EB	1	1.11151	0.01202	92.44	<.0001	1.37190
SfTemp	SfTemp	1	0.08761	0.00382	22.96	<.0001	2.71779
SubTemp	SubTemp	1	-0.06250	0.01974	-3.17	0.0015	1.62627
PrecipRate	PrecipRate	1	-16.00398	1.12286	-14.25	<.0001	1.14453
AirTemp	AirTemp	1	-0.02520	0.00822	-3.06	0.0022	2.90765
Dewpoint	Dewpoint	1	-0.01709	0.00605	-2.82	0.0048	1.66662
AvgWindSpeed	AvgWindSpeed	1	-0.09106	0.00591	-15.41	<.0001	1.35044
Visibility	Visibility	1	0.00001980	0.00000729	2.71	0.0066	1.62088
wd2		1	-4.11309	0.41952	-9.80	<.0001	1.16159
wd3		1	-1.92954	0.35812	-5.39	<.0001	1.15844
wd5		1	2.02958	0.97321	2.09	0.0370	1.00995
wd6		1	0.85562	0.11015	7.77	<.0001	1.26409


AvgSpd = -2.2439 +1.1115 EB +0.0876 SfTemp -0.0625 SubTemp -16.004 PrecipRate
-0.0252 AirTemp -0.0171 Dewpoint -0.0911 AvgWndSpeed +198E-7 Visibility
-4.1131 wd2 -1.9295 wd3 +2.0296 wd5 +0.8556 wd6
N
17552
Rsq
0.5188
Adj Rsq
0.5185
RMSE
6.4156
Residual
Predicted Value
60
40
20
0
-20
-40
-60
-80
30
35
40
45
50
55
60
65
70
75

Response to VSL with WB Initial Model

The SAS System 14:54 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpd AvgSpd

Number of Observations Read	20720
Number of Observations Used	17476
Number of Observations with Missing Values	3244

Analysis of Variance

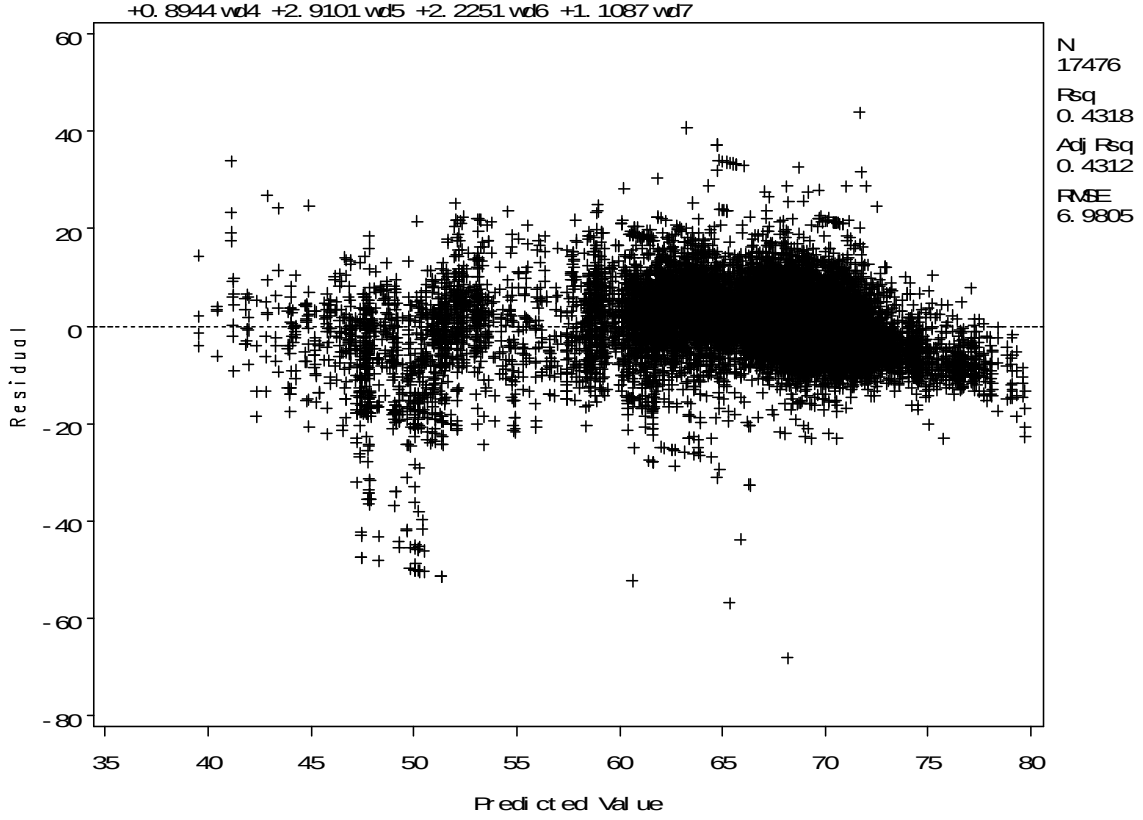
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	19	646463	34024	698.26	<.0001
Error	17456	850579	48.72700		
Corrected Total	17475	1497041			

Root MSE	6.98047	R-Square	0.4318
Dependent Mean	66.36003	Adj R-Sq	0.4312
Coeff Var	10.51909		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	22.14787	1.42155	15.58	<.0001	0
WB	WB	1	0.70201	0.01223	57.42	<.0001	2.10565
SfStatus	SfStatus	1	1.62305	0.32993	4.92	<.0001	8.39679
SfTemp	SfTemp	1	0.05850	0.00611	9.57	<.0001	5.87909
SubTemp	SubTemp	1	-0.05938	0.02250	-2.64	0.0083	1.74265
ChemFactor	ChemFactor	1	0.10472	0.01127	9.29	<.0001	2.59314
PrecipRate	PrecipRate	1	-18.56075	1.25018	-14.85	<.0001	1.19829
AirTemp	AirTemp	1	-0.01581	0.01819	-0.87	0.3849	11.94819
RH	RH	1	-0.04625	0.01029	-4.49	<.0001	31.25324
Dewpoint	Dewpoint	1	0.08725	0.01962	4.45	<.0001	14.61839
AvgWindSpeed	AvgWindSpeed	1	0.02059	0.02274	0.91	0.3652	16.70295
GustWindSpeed	GustWindSpeed	1	-0.13539	0.01819	-7.44	<.0001	16.73799
Visibility	Visibility	1	0.00036749	0.00001055	34.84	<.0001	2.74696
wd1		1	-0.90852	1.15327	-0.79	0.4308	1.30659
wd2		1	-1.19340	0.71406	-1.67	0.0947	2.80196
wd3		1	0.38937	0.66592	0.58	0.5588	3.38303
wd4		1	0.89438	2.52711	0.35	0.7234	1.04802
wd5		1	2.91007	1.19039	2.44	0.0145	1.27635
wd6		1	2.22507	0.55817	3.99	<.0001	27.26052
wd7		1	1.10869	0.55452	2.00	0.0456	25.69715

AvgSpd = 22.148 +0.702 VB3 +1.623 SfStatus +0.0585 SfTemp -0.0594 SubTemp +0.1047 ChemFactor
-18.561 PrecipRate -0.0158 AirTemp -0.0463 RH +0.0873 Dewpoint +0.0206 AvgWndSpeed
-0.1354 GustWndSpeed +0.0004 Visibility -0.9085 wd1 -1.1934 wd2 +0.3894 wd3
+0.8944 wd4 +2.9101 wd5 +2.2251 wd6 +1.1087 wd7



Response to VSL with WB Final Model

The SAS System 14:54 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpd AvgSpd

Number of Observations Read	20720
Number of Observations Used	17476
Number of Observations with Missing Values	3244

Analysis of Variance

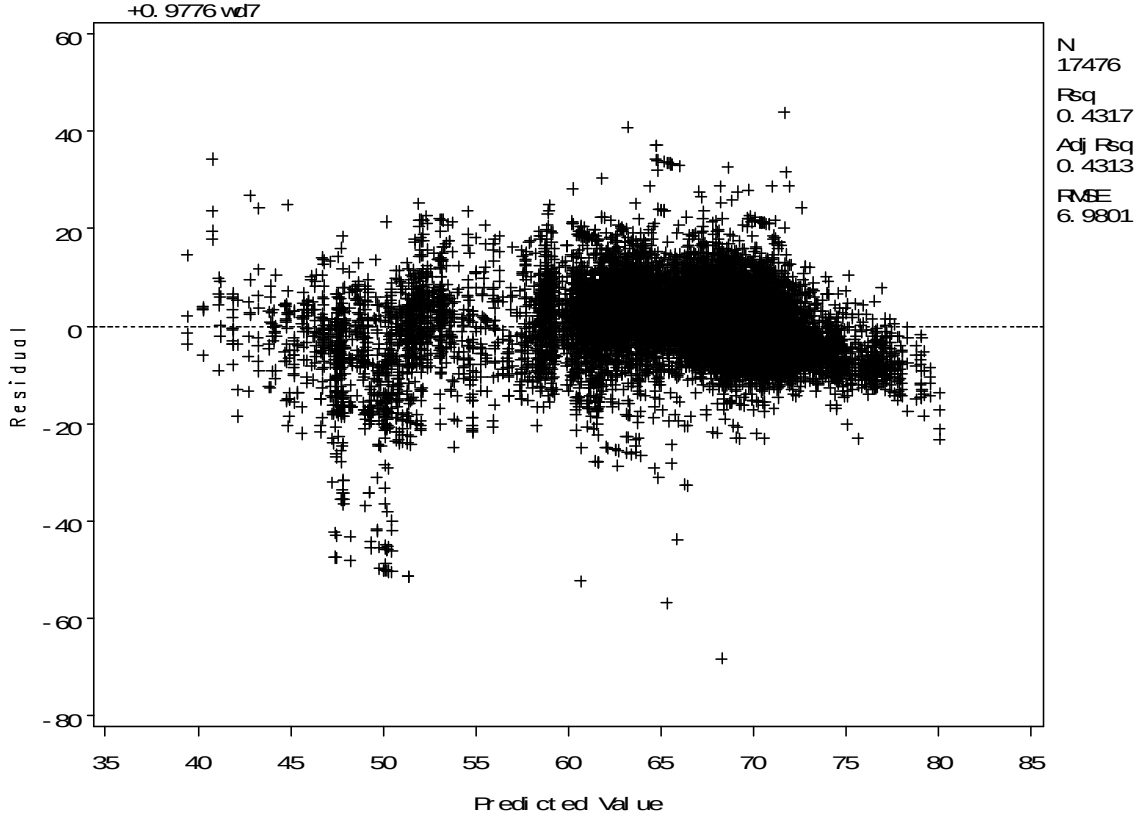
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	14	646309	46165	947.52	<.0001
Error	17461	850732	48.72186		
Corrected Total	17475	1497041			

Root MSE	6.98010	R-Square	0.4317
Dependent Mean	66.36003	Adj R-Sq	0.4313
Coeff Var	10.51854		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	21.63848	1.25471	17.25	<.0001	0
WB	WB	1	0.70191	0.01222	57.44	<.0001	2.10368
SfStatus	SfStatus	1	1.77741	0.29113	6.11	<.0001	6.53832
SfTemp	SfTemp	1	0.05664	0.00548	10.34	<.0001	4.72262
SubTemp	SubTemp	1	-0.06492	0.02110	-3.08	0.0021	1.53251
ChemFactor	ChemFactor	1	0.10869	0.01020	10.65	<.0001	2.12640
PrecipRate	PrecipRate	1	-18.89816	1.22964	-15.37	<.0001	1.15936
RH	RH	1	-0.03713	0.00558	-6.65	<.0001	9.19316
Dewpoint	Dewpoint	1	0.07115	0.01152	6.18	<.0001	5.03675
GustWindSpeed	GustWindSpeed	1	-0.11999	0.00542	-22.14	<.0001	1.48682
Visibility	Visibility	1	0.00036682	0.00001049	34.96	<.0001	2.71721
wd2		1	-1.39194	0.51995	-2.68	0.0074	1.48580
wd5		1	2.77987	1.10074	2.53	0.0116	1.09145
wd6		1	2.10319	0.33770	6.23	<.0001	9.97964
wd7		1	0.97760	0.32394	3.02	0.0025	8.77016

AvgSpd = 21.638 +0.7019 VB3 +1.7774 SfStatus +0.0566 SfTemp -0.0649 SubTemp
+0.1087 ChemFactor -18.898 PrecipRate -0.0371 RH +0.0711 Dewpoint
-0.12 GustWindSpeed +0.0004 Visibility -1.3919 wd2 +2.7799 wd5 +2.1032 wd6
+0.9776 wd7



Response to VSL with WB Minus Outliers Initial Model

The SAS System 14:58 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpd AvgSpd

Number of Observations Read	20720
Number of Observations Used	17476
Number of Observations with Missing Values	3244

Analysis of Variance

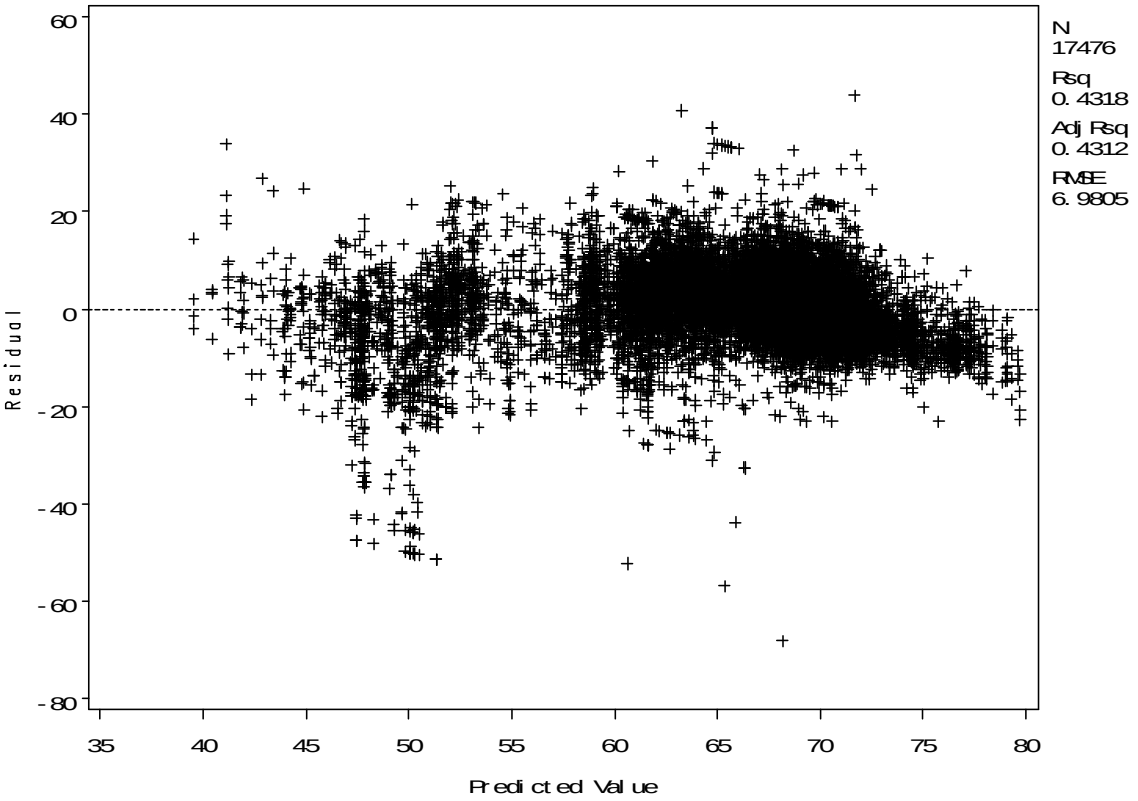
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	19	646463	34024	698.26	<.0001
Error	17456	850579	48.72700		
Corrected Total	17475	1497041			

Root MSE	6.98047	R-Square	0.4318
Dependent Mean	66.36003	Adj R-Sq	0.4312
Coeff Var	10.51909		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	22.14787	1.42155	15.58	<.0001	0
WB	WB	1	0.70201	0.01223	57.42	<.0001	2.10565
SfStatus	SfStatus	1	1.62305	0.32993	4.92	<.0001	8.39679
SfTemp	SfTemp	1	0.05850	0.00611	9.57	<.0001	5.87909
SubTemp	SubTemp	1	-0.05938	0.02250	-2.64	0.0083	1.74265
ChemFactor	ChemFactor	1	0.10472	0.01127	9.29	<.0001	2.59314
PrecipRate	PrecipRate	1	-18.56075	1.25018	-14.85	<.0001	1.19829
AirTemp	AirTemp	1	-0.01581	0.01819	-0.87	0.3849	11.94819
RH	RH	1	-0.04625	0.01029	-4.49	<.0001	31.25324
Dewpoint	Dewpoint	1	0.08725	0.01962	4.45	<.0001	14.61839
AvgWindSpeed	AvgWindSpeed	1	0.02059	0.02274	0.91	0.3652	16.70295
GustWindSpeed	GustWindSpeed	1	-0.13539	0.01819	-7.44	<.0001	16.73799
Visibility	Visibility	1	0.00036749	0.00001055	34.84	<.0001	2.74696
wd1		1	-0.90852	1.15327	-0.79	0.4308	1.30659
wd2		1	-1.19340	0.71406	-1.67	0.0947	2.80196
wd3		1	0.38937	0.66592	0.58	0.5588	3.38303
wd4		1	0.89438	2.52711	0.35	0.7234	1.04802
wd5		1	2.91007	1.19039	2.44	0.0145	1.27635
wd6		1	2.22507	0.55817	3.99	<.0001	27.26052
wd7		1	1.10869	0.55452	2.00	0.0456	25.69715

AvgSpd = 22.148 +0.702 VB3 +1.623 SfStatus +0.0585 SfTemp -0.0594 SubTemp +0.1047 ChemFactor
-18.561 PrecipRate -0.0158 AirTemp -0.0463 RH +0.0873 Dewpoint +0.0206 AvgWindSpeed
-0.1354 GustWindSpeed +0.0004 Visibility -0.9085 wd1 -1.1934 wd2 +0.3894 wd3
+0.8944 wd4 +2.9101 wd5 +2.2251 wd6 +1.1087 wd7



Response to VSL with WB Minus Outliers Final Model

The SAS System 14:58 Monday, May 25, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: AvgSpd AvgSpd

Number of Observations Read	20720
Number of Observations Used	17476
Number of Observations with Missing Values	3244

Analysis of Variance

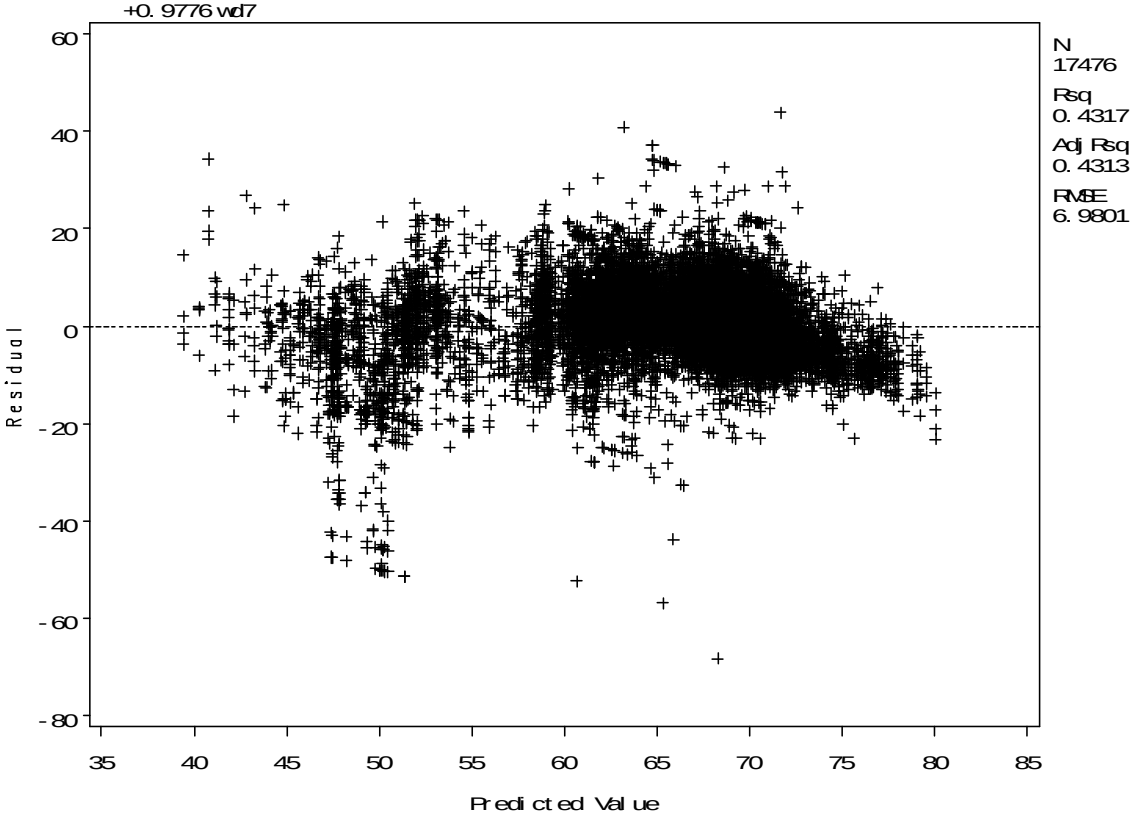
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	14	646309	46165	947.52	<.0001
Error	17461	850732	48.72186		
Corrected Total	17475	1497041			

Root MSE	6.98010	R-Square	0.4317
Dependent Mean	66.36003	Adj R-Sq	0.4313
Coeff Var	10.51854		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	21.63848	1.25471	17.25	<.0001	0
WB	WB	1	0.70191	0.01222	57.44	<.0001	2.10368
SfStatus	SfStatus	1	1.77741	0.29113	6.11	<.0001	6.53832
SfTemp	SfTemp	1	0.05664	0.00548	10.34	<.0001	4.72262
SubTemp	SubTemp	1	-0.06492	0.02110	-3.08	0.0021	1.53251
ChemFactor	ChemFactor	1	0.10869	0.01020	10.65	<.0001	2.12640
PrecipRate	PrecipRate	1	-18.89816	1.22964	-15.37	<.0001	1.15936
RH	RH	1	-0.03713	0.00558	-6.65	<.0001	9.19316
Dewpoint	Dewpoint	1	0.07115	0.01152	6.18	<.0001	5.03675
GustWindSpeed	GustWindSpeed	1	-0.11999	0.00542	-22.14	<.0001	1.48682
Visibility	Visibility	1	0.00036682	0.00001049	34.96	<.0001	2.71721
wd2		1	-1.39194	0.51995	-2.68	0.0074	1.48580
wd5		1	2.77987	1.10074	2.53	0.0116	1.09145
wd6		1	2.10319	0.33770	6.23	<.0001	9.97964
wd7		1	0.97760	0.32394	3.02	0.0025	8.77016

AvgSpd = 21.638 +0.7019 VB3 +1.7774 SfStatus +0.0566 SfTemp -0.0649 SubTemp
+0.1087 ChenFactor -18.898 PrecipRate -0.0371 RH +0.0711 Dewpoint
-0.12 GustWindSpeed +0.0004 Visibility -1.3919 wd2 +2.7799 wd5 +2.1032 wd6
+0.9776 wd7



Appendix D

Data Analysis

256.25 East Bound October 15th to December 15th 2009					
	Intial Model			Final Model	
Variable	Coefficient	P-Value	Variable	Coefficient	P-Value
Intercept	34.286	<.0001	Intercept	34.2042	<.0001
DN	1.0358	<.0001	DN	1.0344	<.0001
EB	0.5925	<.0001	EB	0.5926	<.0001
SfStatus	0.8705	<.0001	SfStatus	0.872	<.0001
SfTemp	0.0672	<.0001	SfTemp	0.0676	<.0001
SubTemp	-0.0887	<.0001	SubTemp	-0.0888	<.0001
AirTemp	-0.104	<.0001	AirTemp	-0.1044	<.0001
RH	-0.0373	<.0001	RH	-0.0372	<.0001
Dewpoint	0.0738	<.0001	Dewpoint	0.0737	<.0001
AvgWindSpeed	0.0122	0.1572	AvgWindSpeed	0.0095	<.0001
GustWindSpeed	-0.002	0.7753	wd2	-0.8107	<.0001
wd1	0.011	0.9564	wd3	0.4457	<.0001
wd2	-0.8782	<.0001	wd4	-0.5844	0.0132
wd3	0.3793	0.0025	wd6	-0.1179	0.0194
wd4	-0.6502	0.0098	PrecipType	1.4825	<.0001
wd5	-0.1888	0.3248	Visibility	0.0001	<.0001
wd6	-0.1927	0.0838			
wd7	-0.0754	0.4737			
PrecipType	1.4828	<.0001			
Visibility	0.0001	<.0001			

260.20 East Bound October 15th to December 15th 2009					
	Intial Model			Final Model	
Variable	Coefficient	P-Value	Variable	Coefficient	P-Value
Intercept	23.0246	<.0001	**Intercept**	22.85	<.0001
DN	1.18	<.0001	**DN**	1.1798	<.0001
EB	0.6497	<.0001	**EB**	0.6491	<.0001
SfStatus	0.9333	<.0001	**SfStatus**	0.9164	<.0001
SfTemp	0.0819	<.0001	**SfTemp**	0.0845	<.0001
SubTemp	-0.0159	0.0005	**SubTemp**	-0.0138	0.002
AirTemp	-0.0853	<.0001	**AirTemp**	-0.0877	<.0001
RH	-0.0204	<.0001	**RH**	-0.02	<.0001
Dewpoint	0.04	<.0001	**Dewpoint**	0.039	<.0001
AvgWindSpeed	0.0373	<.0001	**AvgWindSpeed**	0.0382	<.0001
GustWindSpeed	-0.0825	<.0001	**GustWindSpeed**	-0.0835	<.0001
wd1	-0.3901	0.0308	**wd2**	-0.9372	<.0001
wd2	-1.0412	<.0001	**wd3**	0.2912	0.0004
wd3	0.191	0.0812	**wd4**	-0.7513	0.0011
wd4	-0.8697	0.0003	**PrecipType**	1.6741	<.0001
wd5	-0.423	0.0172	**Visibility**	0.0001	<.0001
wd6	-0.1564	0.1111			
wd7	-0.0695	0.4472			
PrecipType	1.6663	<.0001			
Visibility	0.0001	0.0001			

263.50 East Bound October 15th to December 15th 2009					
	Intial Model			Final Model	
Variable	Coefficient	P-Value	Variable	Coefficient	P-Value
Intercept	21.0286	<.0001	Intercept	20.361	<.0001
DN	1.7473	<.0001	DN	1.749	<.0001
EB	0.7097	<.0001	EB	0.7119	<.0001
SfStatus	0.6727	<.0001	SfStatus	0.7246	<.0001
SfTemp	0.0256	<.0001	SfTemp	0.0245	<.0001
SubTemp	0.1236	<.0001	SubTemp	0.1238	<.0001
AirTemp	-0.0511	<.0001	AirTemp	-0.0418	<.0001
RH	-0.0065	0.1776	Dewpoint	-0.0451	<.0001
Dewpoint	-0.0353	<.0001	AvgWindSpeed	0.0441	0.0001
AvgWindSpeed	0.045	<.0001	GustWindSpeed	-0.0882	<.0001
GustWindSpeed	-0.0892	<.0001	wd2	-0.3311	0.0143
wd1	0.1009	0.7501	wd7	0.2704	<.0001
wd2	-0.2534	0.1409	PrecipType	1.4429	<.0001
wd3	0.0437	0.8113	Visibility	-0.0001	<.0001
wd4	0.5811	0.1069			
wd5	-0.0923	0.751			
wd6	0.0614	0.6658			
wd7	0.3252	0.0147			
PrecipType	1.3887	<.0001			
Visibility	0.0001	<.0001			

266.40 East Bound October 15th to December 15th 2009					
	Intial Model			Final Model	
Variable	Coefficient	P-Value	Variable	Coefficient	P-Value
Intercept	17.5585	<.0001	**Intercept**	17.4397	<.0001
DN	1.7418	<.0001	**DN**	1.7436	<.0001
EB	0.7186	<.0001	**EB**	0.7185	<.0001
SfStatus	1.3083	<.0001	**SfStatus**	1.292	<.0001
SfTemp	0.1422	<.0001	**SfTemp**	0.1437	<.0001
SubTemp	-0.0681	<.0001	**SubTemp**	-0.0673	<.0001
AirTemp	-0.1292	<.0001	**AirTemp**	-0.1301	<.0001
RH	-0.0428	<.0001	**RH**	-0.0417	<.0001
Dewpoint	0.0798	<.0001	**Dewpoint**	0.0789	<.0001
AvgWindSpeed	0.0236	0.0415	**AvgWindSpeed**	0.0231	0.045
GustWindSpeed	-0.0356	0.0001	**GustWindSpeed**	-0.0356	0.0001
wd1	-0.6066	0.0166	**wd1**	-0.6363	0.0054
wd2	-1.2879	<.0001	**wd2**	-1.3172	<.0001
wd3	-1.3721	<.0001	**wd3**	-1.4024	<.0001
wd4	-1.9681	<.0001	**wd4**	-1.9847	<.0001
wd5	-0.0518	0.8367	**PrecipType**	2.2691	<.0001
wd6	-0.0236	0.8676			
wd7	0.0727	0.5832			
PrecipType	2.2724	<.0001			
Visibility	0.0001	0.3203			

268.10 East Bound October 15th to December 15th 2009					
	Intial Model			Final Model	
Variable	Coefficient	P-Value	Variable	Coefficient	P-Value
Intercept	28.4606	<.0001	**Intercept**	28.3969	<.0001
DN	2.5821	<.0001	**DN**	2.5809	<.0001
EB	0.6689	<.0001	**EB**	0.669	<.0001
SfStatus	0.6398	<.0001	**SfStatus**	0.6442	<.0001
SfTemp	0.0352	<.0001	**SfTemp**	0.0339	<.0001
SubTemp	-0.0138	0.0036	**SubTemp**	-0.0145	0.0018
AirTemp	-0.1047	<.0001	**AirTemp**	-0.1035	<.0001
RH	-0.0672	<.0001	**RH**	-0.0672	<.0001
Dewpoint	0.0954	<.0001	**Dewpoint**	0.0955	<.0001
AvgWindSpeed	0.0174	0.0431	**AvgWindSpeed**	0.018	0.0346
GustWindSpeed	-0.0863	<.0001	**GustWindSpeed**	-0.0864	<.0001
wd1	-0.2213	0.2375	**wd2**	-0.4348	<.0001
wd2	-0.5239	<.0001	**wd3**	0.632	<.0001
wd3	0.5436	<.0001	**wd4**	-0.5692	0.0146
wd4	-0.6526	0.0082	**PrecipType**	2.5735	<.0001
wd5	-0.155	0.4124	**Visibility**	0.0001	<.0001
wd6	-0.0459	0.6607			
wd7	-0.1155	0.2381			
PrecipType	2.5724	<.0001			
Visibility	0.0001	<.0001			

278.13 East Bound October 15th to December 15th 2009					
	Intial Model			Final Model	
Variable	Coefficient	P-Value	Variable	Coefficient	P-Value
Intercept	19.8191	<.0001	Intercept	19.8191	<.0001
DN	1.1796	<.0001	DN	1.1796	<.0001
EB	0.7992	<.0001	EB	0.7992	<.0001
SfStatus	0.6601	<.0001	SfStatus	0.6601	<.0001
SfTemp	0.0616	<.0001	SfTemp	0.0616	<.0001
SubTemp	-0.0408	<.0001	SubTemp	-0.0408	<.0001
AirTemp	-0.0462	<.0001	AirTemp	-0.0462	<.0001
RH	-0.0079	0.0088	RH	-0.0079	0.0088
Dewpoint	0.0336	<.0001	Dewpoint	0.0336	<.0001
AvgWindSpeed	0.0303	0.0001	AvgWindSpeed	0.0303	0.0001
GustWindSpeed	-0.0406	<.0001	GustWindSpeed	-0.0406	<.0001
wd1	-0.738	<.0001	wd1	-0.738	<.0001
wd2	-1.5073	<.0001	wd2	-1.5073	<.0001
wd3	-0.9279	<.0001	wd3	-0.9279	<.0001
wd4	-1.2713	<.0001	wd4	-1.2713	<.0001
wd5	-0.8631	<.0001	wd5	-0.8631	<.0001
wd6	-0.6146	<.0001	wd6	-0.6146	<.0001
wd7	-0.3215	0.0003	wd7	-0.3215	0.0003
PrecipType	1.5239	<.0001	PrecipType	1.5239	<.0001
Visibility	0.0001	0.0002	Visibility	0.0001	0.0002

282.50 East Bound October 15th to December 15th 2009					
	Intial Model			Final Model	
Variable	Coefficient	P-Value	Variable	Coefficient	P-Value
Intercept	16.3235	<.0001	Intercept	16.2516	<.0001
DN	1.5128	<.0001	DN	1.5165	<.0001
EB	0.7988	<.0001	EB	0.7987	<.0001
SfStatus	0.6948	<.0001	SfStatus	0.6924	<.0001
SfTemp	0.052	<.0001	SfTemp	0.052	<.0001
SubTemp	-0.0016	0.6816	AirTemp	-0.0548	<.0001
AirTemp	-0.0542	<.0001	RH	-0.0212	<.0001
RH	-0.0212	<.0001	Dewpoint	0.0284	<.0001
Dewpoint	0.0287	<.0001	AvgWindSpeed	0.048	<.0001
AvgWindSpeed	0.0477	<.0001	GustWindSpeed	-0.0761	<.0001
GustWindSpeed	-0.0761	<.0001	wd2	-0.9244	<.0001
wd1	-0.1234	0.4312	wd3	-0.8596	<.0001
wd2	-0.9591	<.0001	wd4	-1.4668	<.0001
wd3	-0.8902	<.0001	wd5	-0.8564	<.0001
wd4	-1.5003	<.0001	wd6	-0.3008	0.0003
wd5	-0.8886	<.0001	wd7	-0.3024	<.0001
wd6	-0.3294	0.0003	PrecipType	0.9227	<.0001
wd7	-0.3284	0.0001	Visibility	0.0001	<.0001
PrecipType	0.9198	<.0001			
Visibility	0.0001	<.0001			

288.30 East Bound October 15th to December 15th 2009					
	Intial Model			Final Model	
Variable	Coefficient	P-Value	Variable	Coefficient	P-Value
Intercept	27.9968	<.0001	Intercept	27.4579	<.0001
DN	0.8359	<.0001	DN	0.8664	<.0001
EB	0.7146	<.0001	EB	0.716	<.0001
SfStatus	0.1901	0.038	SfStatus	0.2055	0.0234
SfTemp	0.037	<.0001	SfTemp	0.0357	<.0001
SubTemp	-0.0134	0.0539	AirTemp	-0.0893	<.0001
AirTemp	-0.0866	<.0001	RH	-0.0484	<.0001
RH	-0.0488	<.0001	Dewpoint	0.069	<.0001
Dewpoint	0.0705	<.0001	AvgWindSpeed	0.0446	<.0001
AvgWindSpeed	0.0399	0.0002	GustWindSpeed	-0.0555	<.0001
GustWindSpeed	-0.0557	<.0001	wd2	-0.7474	<.0001
wd1	-0.1804	0.4132	wd3	-0.5394	<.0001
wd2	-0.7728	<.0001	wd5	-0.6575	0.0011
wd3	-0.5412	0.0002	wd7	0.1564	0.0101
wd4	-0.466	0.1052	PrecipType	1.244	<.0001
wd5	-0.6365	0.0059	Visibility	0.0001	<.0001
wd6	0.0915	0.4951			
wd7	0.2169	0.0815			
PrecipType	1.2352	<.0001			
Visibility	0.0001	<.0001			

256.25 West Bound October 15th to December 15th 2009					
	Intial Model			Final Model	
Variable	Coefficient	P-Value	Variable	Coefficient	P-Value
Intercept	28.946	<.0001	Intercept	28.7894	<.0001
DN	1.7379	<.0001	DN	1.7458	<.0001
WB	0.585	<.0001	WB	0.5864	<.0001
SfStatus	0.6538	<.0001	SfStatus	0.681	<.0001
SfTemp	0.0456	<.0001	SfTemp	0.0439	<.0001
SubTemp	0.0636	<.0001	SubTemp	0.0638	<.0001
AirTemp	-0.0731	<.0001	AirTemp	-0.0689	<.0001
RH	-0.0175	<.0001	RH	-0.016	<.0001
Dewpoint	0.0035	0.4698	AvgWindSpeed	0.054	<.0001
AvgWindSpeed	0.0532	<.0001	GustWindSpeed	-0.0886	<.0001
GustWindSpeed	-0.0885	<.0001	wd2	-0.7473	<.0001
wd1	0.2925	0.103	wd3	0.5754	<.0001
wd2	-0.7102	<.0001	wd4	-0.7036	0.0007
wd3	0.6188	<.0001	PrecipType	1.6275	<.0001
wd4	-0.6551	0.0032			
wd5	-0.1145	0.5027			
wd6	0.0841	0.4015			
wd7	0.0027	0.9773			
PrecipType	1.6112	<.0001			
Visibility	0.0001	0.2863			

260.20 West Bound October 15th to December 15th 2009					
	Intial Model			Final Model	
Variable	Coefficient	P-Value	Variable	Coefficient	P-Value
Intercept	25.7502	<.0001	**Intercept**	25.7388	<.0001
DN	1.6575	<.0001	**DN**	1.6542	<.0001
WB	0.6677	<.0001	**WB**	0.6682	<.0001
SfStatus	0.3391	<.0001	**SfStatus**	0.3353	<.0001
SfTemp	0.0406	<.0001	**SfTemp**	0.0402	<.0001
SubTemp	0.0781	<.0001	**SubTemp**	0.0787	<.0001
AirTemp	-0.0999	<.0001	**AirTemp**	-0.1	<.0001
RH	-0.0396	<.0001	**RH**	-0.0398	<.0001
Dewpoint	0.0317	<.0001	**Dewpoint**	0.032	<.0001
AvgWindSpeed	0.0237	0.0113	**AvgWindSpeed**	0.0254	0.0062
GustWindSpeed	-0.0449	<.0001	**GustWindSpeed**	-0.0451	<.0001
wd1	0.0078	0.9692	**wd2**	-0.3702	<.0001
wd2	-0.3538	0.0042	**wd3**	0.7644	<.0001
wd3	0.7835	<.0001	**wd7**	-0.126	0.0116
wd4	-0.4205	0.1177	**PrecipType**	1.8504	<.0001
wd5	-0.0707	0.7294	**Visibility**	0.0001	0.0489
wd6	0.0648	0.5607			
wd7	-0.0862	0.4074			
PrecipType	1.8525	<.0001			
Visibility	0.0001	0.0603			

263.50 West Bound October 15th to December 15th 2009					
	Intial Model			Final Model	
Variable	Coefficient	P-Value	Variable	Coefficient	P-Value
Intercept	17.2866	<.0001	**Intercept**	17.0088	<.0001
DN	0.8959	<.0001	**DN**	0.8949	<.0001
WB	0.831	<.0001	**WB**	0.8302	<.0001
SfStatus	0.571	<.0001	**SfStatus**	0.5637	<.0001
SfTemp	0.1057	<.0001	**SfTemp**	0.1062	<.0001
SubTemp	0.0247	0.003	**SubTemp**	0.0241	0.0008
AirTemp	-0.1572	<.0001	**AirTemp**	-0.1578	<.0001
RH	-0.0315	<.0001	**RH**	-0.0304	<.0001
Dewpoint	0.0288	0.003	**Dewpoint**	0.0282	0.0032
AvgWindSpeed	0.0109	0.4204	**wd2**	-1.5899	<.0001
GustWindSpeed	-0.0078	0.4711	**wd3**	-0.546	0.0017
wd1	-0.6221	0.077	**wd5**	-0.6436	0.0295
wd2	-1.8048	<.0001	**wd6**	-0.4693	<.0001
wd3	-0.7725	0.0003	**PrecipType**	0.8684	<.0001
wd4	-0.8032	0.0635			
wd5	-0.8725	0.0075			
wd6	-0.7223	<.0001			
wd7	-0.2589	0.0935			
PrecipType	0.8763	<.0001			
Visibility	-0.0001	0.4077			

266.40 West Bound October 15th to December 15th 2009					
	Intial Model			Final Model	
Variable	Coefficient	P-Value	Variable	Coefficient	P-Value
Intercept	13.7452	<.0001	Intercept	13.7068	<.0001
DN	1.6399	<.0001	DN	1.6357	<.0001
WB	0.8556	<.0001	WB	0.8547	<.0001
SfStatus	1.0632	<.0001	SfStatus	1.0629	<.0001
SfTemp	0.0137	0.0002	SfTemp	0.0142	0.0001
SubTemp	0.0455	<.0001	SubTemp	0.0463	<.0001
AirTemp	-0.03	<.0001	AirTemp	-0.0315	<.0001
RH	-0.0367	<.0001	RH	-0.0371	<.0001
Dewpoint	0.0523	<.0001	Dewpoint	0.0527	<.0001
AvgWindSpeed	0.0426	<.0001	AvgWindSpeed	0.0422	<.0001
GustWindSpeed	-0.1142	<.0001	GustWindSpeed	-0.1138	<.0001
wd1	0.1701	0.3565	wd2	-0.3434	0.0001
wd2	-0.4395	0.0002	wd6	0.2749	0.0002
wd3	-0.2099	0.1034	wd7	0.3862	<.0001
wd4	-0.3703	0.1261	PrecipType	1.3912	<.0001
wd5	-0.1501	0.4032	Visibility	0.0001	0.0017
wd6	0.182	0.0796			
wd7	0.2953	0.0026			
PrecipType	1.3859	<.0001			
Visibility	0.0001	0.0012			

268.10 West Bound October 15th to December 15th 2009					
	Intial Model			Final Model	
Variable	Coefficient	P-Value	Variable	Coefficient	P-Value
Intercept	16.7174	<.0001	Intercept	16.6968	<.0001
DN	1.3755	<.0001	DN	1.3695	<.0001
WB	0.7761	<.0001	WB	0.7764	<.0001
SfStatus	1.4947	<.0001	SfStatus	1.4972	<.0001
SfTemp	0.1199	<.0001	SfTemp	0.12	<.0001
SubTemp	-0.0454	<.0001	SubTemp	-0.0459	<.0001
AirTemp	-0.1221	<.0001	AirTemp	-0.1223	<.0001
RH	-0.0305	<.0001	RH	-0.0304	<.0001
Dewpoint	0.0547	<.0001	Dewpoint	0.0548	<.0001
AvgWindSpeed	0.0144	0.1218	GustWindSpeed	-0.0211	<.0001
GustWindSpeed	-0.0321	<.0001	wd1	-0.9518	<.0001
wd1	-0.9443	<.0001	wd2	-1.6571	<.0001
wd2	-1.6657	<.0001	wd3	-1.5993	<.0001
wd3	-1.6017	<.0001	wd4	-1.5171	<.0001
wd4	-1.5014	<.0001	wd5	-0.7279	0.0003
wd5	-0.7174	0.0003	wd6	-0.386	0.0005
wd6	-0.3958	0.0004	wd7	-0.2093	0.043
wd7	-0.2152	0.0376	PrecipType	2.2673	<.0001
PrecipType	2.2688	<.0001	Visibility	-0.0001	<.0001
Visibility	-0.0001	<.0001			

278.13 West Bound October 15th to December 15th 2009					
	Intial Model			Final Model	
Variable	Coefficient	P-Value	Variable	Coefficient	P-Value
Intercept	25.2313	<.0001	Intercept	25.2092	<.0001
DN	2.142	<.0001	DN	2.1145	<.0001
WB	0.6313	<.0001	WB	0.6318	<.0001
SfStatus	0.7138	<.0001	SfStatus	0.7072	<.0001
SfTemp	0.0245	<.0001	SfTemp	0.0251	<.0001
SubTemp	0.0066	0.2197	RH	-0.0246	<.0001
AirTemp	-0.0021	0.777	Dewpoint	0.0222	<.0001
RH	-0.0252	<.0001	GustWindSpeed	-0.0853	<.0001
Dewpoint	0.0213	0.0003	wd3	1.249	<.0001
AvgWindSpeed	0.0035	0.7115	wd6	0.705	<.0001
GustWindSpeed	-0.0873	<.0001	wd7	0.4677	<.0001
wd1	-0.0801	0.697	PrecipType	1.428	<.0001
wd2	-0.1318	0.3005			
wd3	1.1424	<.0001			
wd4	-0.5001	0.0746			
wd5	-0.1102	0.5928			
wd6	0.5969	<.0001			
wd7	0.3527	0.001			
PrecipType	1.4231	<.0001			
Visibility	-0.0001	0.5872			

282.50 West Bound October 15th to December 15th 2009					
	Intial Model			Final Model	
Variable	Coefficient	P-Value	Variable	Coefficient	P-Value
Intercept	24.99	<.0001	Intercept	25.1285	<.0001
DN	2.0712	<.0001	DN	2.0715	<.0001
WB	0.633	<.0001	WB	0.6333	<.0001
SfStatus	0.8383	<.0001	SfStatus	0.8446	<.0001
SfTemp	0.0292	<.0001	SfTemp	0.0282	<.0001
SubTemp	0.0367	<.0001	SubTemp	0.0366	<.0001
AirTemp	-0.0478	<.0001	AirTemp	-0.0472	<.0001
RH	-0.036	<.0001	RH	-0.0368	<.0001
Dewpoint	0.0488	<.0001	Dewpoint	0.0495	<.0001
AvgWindSpeed	0.0255	0.0034	AvgWindSpeed	0.0258	0.0029
GustWindSpeed	-0.0334	<.0001	GustWindSpeed	-0.0332	<.0001
wd1	0.005	0.9798	wd2	-0.3186	0.0002
wd2	-0.2509	0.0345	wd3	-0.3535	<.0001
wd3	-0.2858	0.0186	wd4	-0.6215	0.0068
wd4	-0.5428	0.0269	PrecipType	1.0147	<.0001
wd5	0.235	0.225			
wd6	0.1041	0.3372			
wd7	0.0632	0.5357			
PrecipType	1.0123	<.0001			
Visibility	0.0001	0.4562			

288.30 East Bound October 15th to December 15th 2009					
	Intial Model			Final Model	
Variable	Coefficient	P-Value	Variable	Coefficient	P-Value
Intercept	32.2517	<.0001	Intercept	32.3119	<.0001
DN	1.8147	<.0001	DN	1.8155	<.0001
WB	0.5404	<.0001	WB	0.5406	<.0001
SfStatus	1.0015	<.0001	SfStatus	1.0067	<.0001
SfTemp	0.0205	<.0001	SfTemp	0.02	<.0001
SubTemp	0.0351	<.0001	SubTemp	0.0349	<.0001
AirTemp	-0.0686	<.0001	AirTemp	-0.0683	<.0001
RH	-0.0353	<.0001	RH	-0.0354	<.0001
Dewpoint	0.0572	<.0001	Dewpoint	0.0575	<.0001
AvgWindSpeed	0.0334	0.0007	AvgWindSpeed	0.0331	0.0008
GustWindSpeed	-0.0377	<.0001	GustWindSpeed	-0.0373	<.0001
wd1	0.066	0.765	wd2	-0.5887	<.0001
wd2	-0.5352	0.0001	wd3	-0.2784	0.0266
wd3	-0.226	0.1212	wd4	-0.9562	0.0007
wd4	-0.8988	0.0022	wd6	0.2863	0.0064
wd5	0.184	0.3941	wd7	0.241	0.0152
wd6	0.3474	0.0089	PrecipType	1.1587	<.0001
wd7	0.2965	0.018	Visibility	0.0001	<.0001
PrecipType	1.159	<.0001			
Visibility	0.0001	<.0001			

256.25 East Bound December 1st to December 2nd INDIVIDUAL 2009					
	Intial Model			Final Model	
Variable	Coefficient	P-Value	Variable	Coefficient	P-Value
Intercept	50.8973	<.0001	Intercept	51.8746	<.0001
EB	0.386	<.0001	EB	0.3843	<.0001
SfStatus	1.2749	0.0046	SfStatus	1.4017	0.0009
SfTemp	-0.0322	0.4538	SubTemp	-0.398	<.0001
SubTemp	-0.3577	0.0426	AirTemp	0.2369	<.0001
AirTemp	0.3543	0.0153	GustWindSpeed	-0.1609	<.0001
RH	0.004	0.9404	wd2	-1.948	<.0001
Dewpoint	-0.0592	0.6548	wd3	-4.0352	<.0001
AvgWindSpeed	-0.0421	0.5558	wd4	3.2238	0.0431
GustWindSpeed	-0.1771	0.0075	wd6	0.9295	0.0415
wd1	-0.9245	0.1435	PrecipType	3.0402	<.0001
wd2	-1.9288	<.0001			
wd3	-4.135	<.0001			
wd4	2.8431	0.0787			
wd5	0	.			
wd6	1.1544	0.0243			
wd7	0.4295	0.1217			
PrecipType	2.7628	<.0001			
Visibility	-0.0001	0.2359			

273.15 East Bound December 1st to December 2nd INDIVIDUAL 2009					
	Intial Model			Final Model	
Variable	Coefficient	P-Value	Variable	Coefficient	P-Value
Intercept	47.7318	<.0001	**Intercept**	48.4331	<.0001
EB	0.6593	<.0001	**EB**	0.6428	<.0001
SfStatus	1.6619	0.0002	**SfStatus**	1.8104	<.0001
SfTemp	-0.0402	0.3508	**SubTemp**	-0.48	0.0039
SubTemp	-0.3761	0.0315	**AirTemp**	-0.4913	<.0001
AirTemp	-0.4625	0.0015	**RH**	-0.1593	0.0002
RH	-0.1876	0.0004	**Dewpoint**	0.6555	<.0001
Dewpoint	0.6971	<.0001	**wd2**	-3.1845	<.0001
AvgWindSpeed	0.1081	0.1094	**wd3**	-4.9356	<.0001
GustWindSpeed	-0.1435	0.0216	**PrecipType**	3.2105	<.0001
wd1	-0.9087	0.133	**Visibility**	0.0003	<.0001
wd2	-3.4565	<.0001			
wd3	-5.2366	<.0001			
wd4	-1.8685	0.1353			
wd5	0	.			
wd6	0.4248	0.4388			
wd7	0.0882	0.7528			
PrecipType	2.7944	<.0001			
Visibility	0.0003	<.0001			

289.50 East Bound December 1st to December 2nd INDIVIDUAL 2009					
	Intial Model			Final Model	
Variable	Coefficient	P-Value	Variable	Coefficient	P-Value
Intercept	83.5342	<.0001	Intercept	87.098	<.0001
EB	0.4374	<.0001	EB	0.4365	<.0001
SfStatus	3.297	<.0001	SfStatus	3.4959	<.0001
SfTemp	0.0673	0.0828	SubTemp	-1.5687	<.0001
SubTemp	-1.3991	<.0001	AirTemp	0.3922	<.0001
AirTemp	0.3173	0.0185	Dewpoint	0.1352	<.0001
RH	-0.0264	0.5911	wd1	-1.4362	0.0006
Dewpoint	0.2185	0.0658	wd2	-3.1759	<.0001
AvgWindSpeed	-0.0261	0.6798	PrecipType	3.7751	<.0001
GustWindSpeed	-0.0484	0.4056	Visibility	-0.0004	<.0001
wd1	-2.2408	<.0001			
wd2	-3.9091	<.0001			
wd3	-1.1821	0.0254			
wd4	-2.2647	0.1071			
wd5	0	.			
wd6	0.5534	0.2547			
wd7	0.3954	0.1235			
PrecipType	3.6711	<.0001			
Visibility	-0.0005	<.0001			

256.25 West Bound December 1st to December 2nd INDIVIDUAL 2009					
	Intial Model			Final Model	
Variable	Coefficient	P-Value	Variable	Coefficient	P-Value
Intercept	45.7144	<.0001	Intercept	43.8196	<.0001
WB	0.3514	<.0001	WB	0.3446	<.0001
SfStatus	1.7021	<.0001	SfStatus	1.5918	<.0001
SfTemp	0.077	0.0489	SfTemp	0.0757	0.0302
SubTemp	-0.0101	0.9525	AirTemp	0.2784	<.0001
AirTemp	0.2447	0.07	RH	-0.0385	0.0061
RH	-0.0549	0.2705	GustWindSpeed	-0.3298	<.0001
Dewpoint	0.0589	0.6301	wd2	-3.3485	<.0001
AvgWindSpeed	0.0576	0.3864	wd3	-5.0602	<.0001
GustWindSpeed	-0.3875	<.0001	wd6	0.9277	0.0424
wd1	-0.8107	0.1442	wd7	1.0422	<.0001
wd2	-3.7332	<.0001	PrecipType	4.4955	<.0001
wd3	-5.5387	<.0001	Visibility	-0.0003	<.0001
wd4	0.4366	0.7545			
wd5	0	.			
wd6	0.9368	0.0474			
wd7	1.0113	<.0001			
PrecipType	4.2302	<.0001			
Visibility	-0.0003	<.0001			

273.15 West Bound December 1st to December 2nd INDIVIDUAL 2009					
	Intial Model			Final Model	
Variable	Coefficient	P-Value	Variable	Coefficient	P-Value
Intercept	51.3912	<.0001	Intercept	51.0752	<.0001
WB	0.5858	<.0001	WB	0.5848	<.0001
SfStatus	0.8989	0.0338	SfStatus	0.8683	0.0332
SfTemp	0.0054	0.8932	AirTemp	-0.3573	0.003
SubTemp	-0.0204	0.9017	RH	-0.2688	<.0001
AirTemp	-0.3416	0.0136	Dewpoint	0.6463	<.0001
RH	-0.2648	<.0001	GustWindSpeed	-0.1235	0.0001
Dewpoint	0.6447	<.0001	wd2	-5.2745	<.0001
AvgWindSpeed	0.0322	0.6379	wd3	-2.73	<.0001
GustWindSpeed	-0.1578	0.012	wd6	1.0885	0.0275
wd1	-0.4504	0.4322	wd7	0.5023	0.0439
wd2	-5.4249	<.0001	PrecipType	2.998	<.0001
wd3	-2.9242	<.0001	Visibility	-0.0002	0.0011
wd4	0.0324	0.9823			
wd5	0	.			
wd6	1.064	0.0321			
wd7	0.4733	0.0651			
PrecipType	2.9386	<.0001			
Visibility	-0.0002	0.0012			

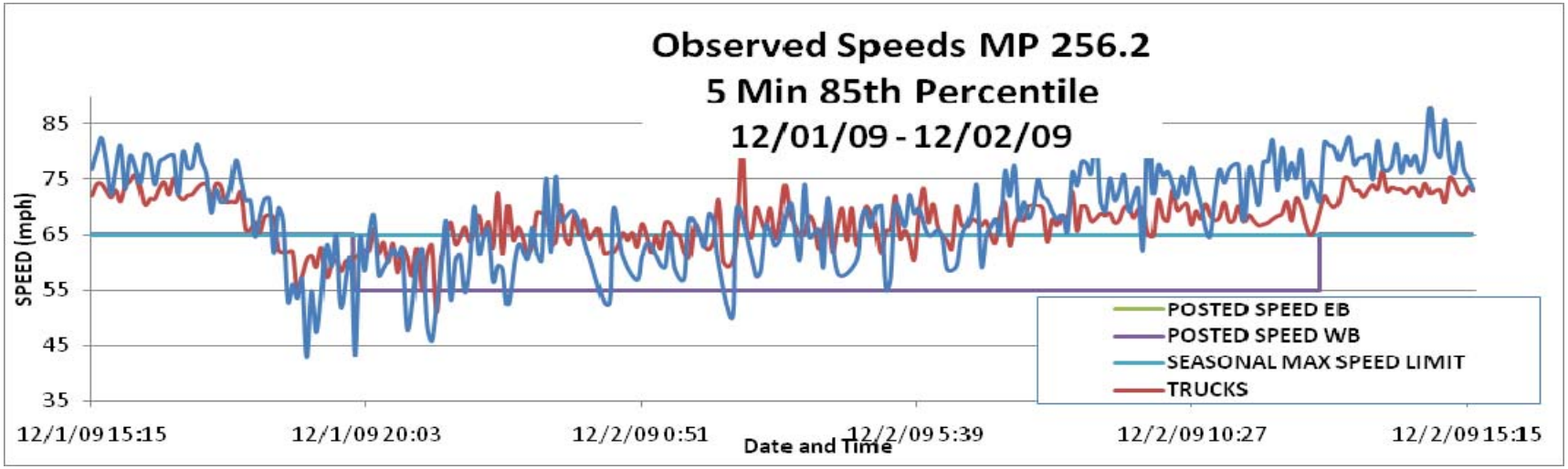
289.50 West Bound December 1st to December 2nd INDIVIDUAL 2009					
	Intial Model			Final Model	
Variable	Coefficient	P-Value	Variable	Coefficient	P-Value
Intercept	75.428	<.0001	Intercept	77.6698	<.0001
WB	0.4786	<.0001	WB	0.4732	<.0001
SfStatus	1.4546	0.0002	SfStatus	1.6248	<.0001
SfTemp	0.092	0.0152	SfTemp	0.0963	0.0039
SubTemp	-1.2832	<.0001	SubTemp	-1.4558	<.0001
AirTemp	0.2179	0.1088	AirTemp	0.2435	<.0001
RH	-0.0373	0.4508	Dewpoint	0.279	<.0001
Dewpoint	0.3479	0.0037	wd1	-1.4631	0.0055
AvgWindSpeed	0.0366	0.5761	wd2	-1.997	<.0001
GustWindSpeed	-0.1017	0.0969	wd3	1.9078	0.0002
wd1	-1.8288	0.0017	PrecipType	3.3779	<.0001
wd2	-2.0953	<.0001	Visibility	-0.0001	0.0216
wd3	1.7432	0.001			
wd4	-2.96	0.0694			
wd5	0	.			
wd6	0.7782	0.0864			
wd7	0.4033	0.105			
PrecipType	3.1839	<.0001			
Visibility	-0.0002	0.0073			

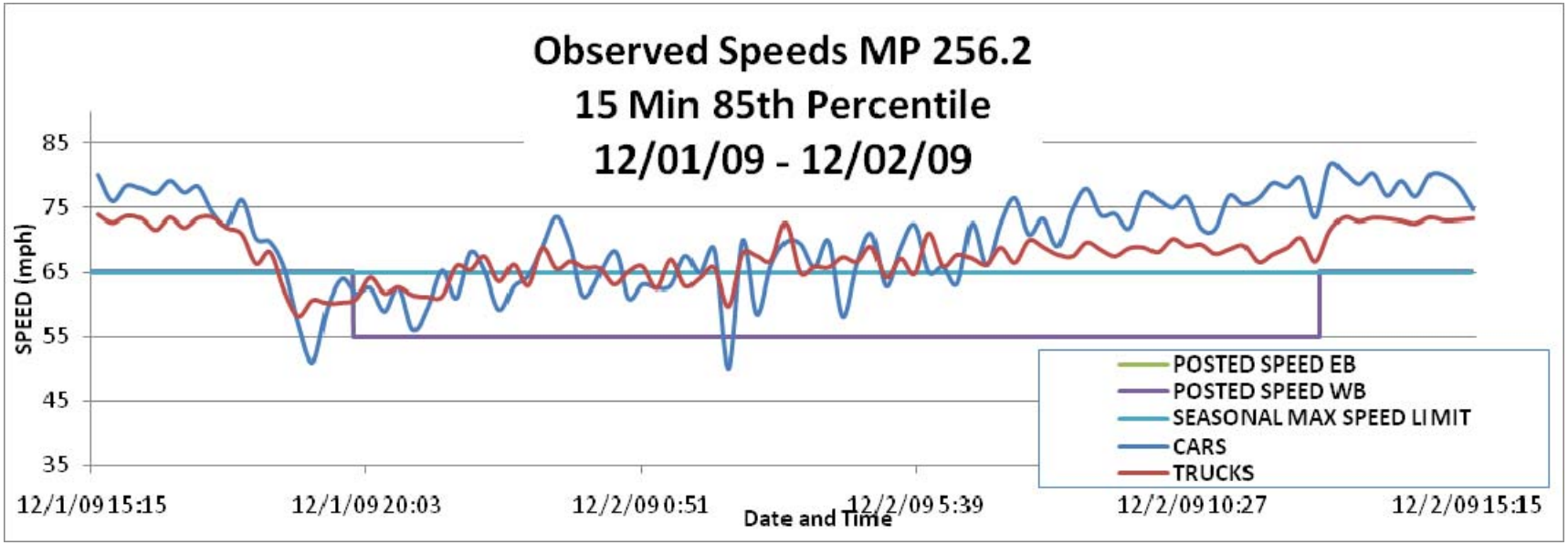
	INDIVIDUAL SPEEDS DECMEBER 1-2, 2009 EAST BOUND		
MILE POSTS	**256.25**	**273.15**	**289.5**
Variable			
Intercept	51.8746	48.4331	87.098
EB	0.3843	0.6428	0.4365
SfStatus	1.4017	1.8104	3.4959
SfTemp	-	-	-
SubTemp	-0.398	-0.48	-1.5687
AirTemp	0.2369	-0.4913	0.3922
RH	-	-0.1593	-
Dewpoint	-	0.6555	0.1352
AvgWindSpeed	-	-	-
GustWindSpeed	-0.1609	-	-
wd1	-	-	-1.4362
wd2	-1.948	-3.1845	-3.1759
wd3	-4.0352	-4.9356	-
wd4	3.2238	-	-
wd5	-	-	-
wd6	0.9295	-	-
wd7	-	-	-
PrecipType	3.0402	3.2105	3.7751
Visibility	-	0.0003	-0.0004

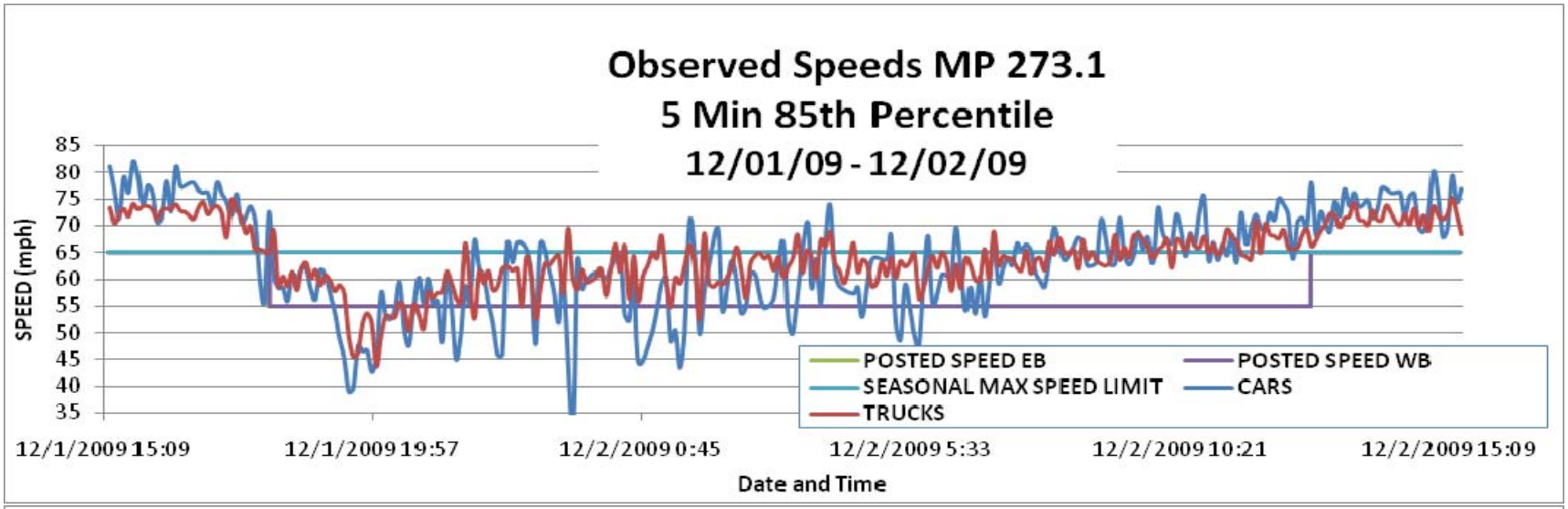
	INDIVIDUAL SPEEDS DECMEBER 1-2, 2009 WEST BOUND		
MILE POSTS	**256.25**	**273.85**	**289.5**
Variable			
Intercept	43.8196	51.0752	77.6698
WB	0.3446	0.5848	0.4732
SfStatus	1.5918	0.8683	1.6248
SfTemp	0.0757	-	0.0963
SubTemp	-	-	-1.4558
AirTemp	0.2784	-0.3573	0.2435
RH	-0.0385	-0.2688	-
Dewpoint	-	0.6463	0.279
AvgWindSpeed	-	-	-
GustWindSpeed	-0.3298	-0.1235	-
wd1	-	-	-1.4631
wd2	-3.3485	-5.2745	-1.997
wd3	-5.0602	-2.73	1.9078
wd4	-	-	-
wd5	-	-	-
wd6	0.9277	1.0885	-
wd7	1.0422	0.5023	-
PrecipType	4.4955	2.998	3.3779
Visibility	-0.0003	-0.0002	-0.0001

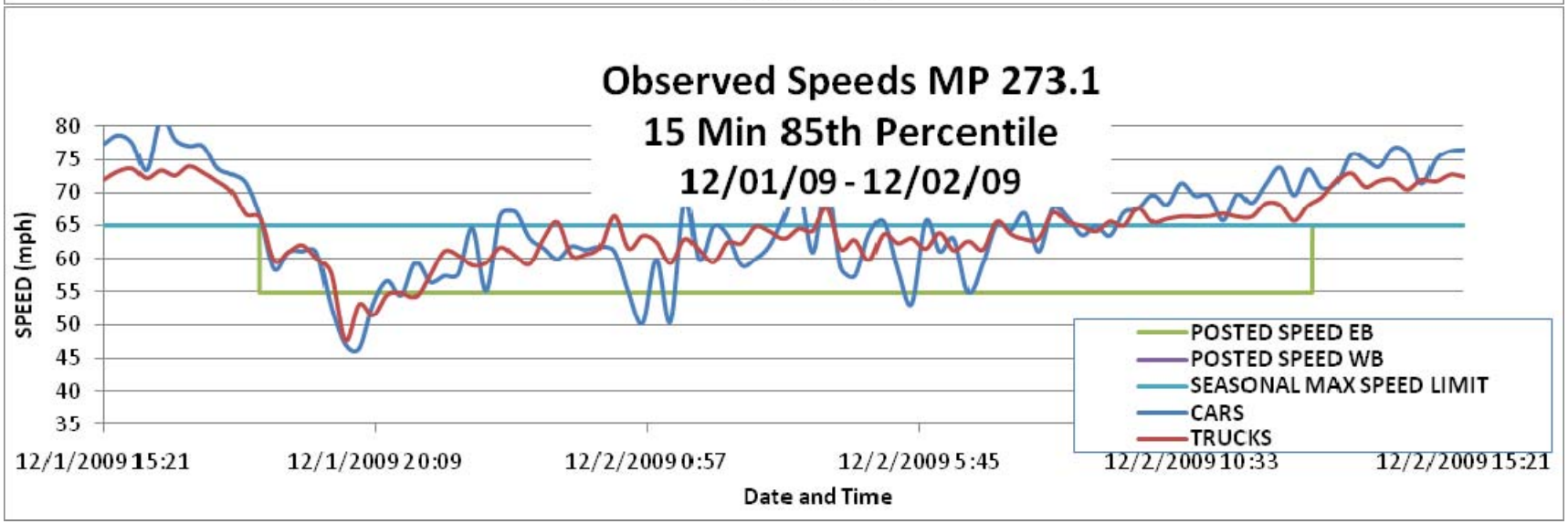
Appendix E

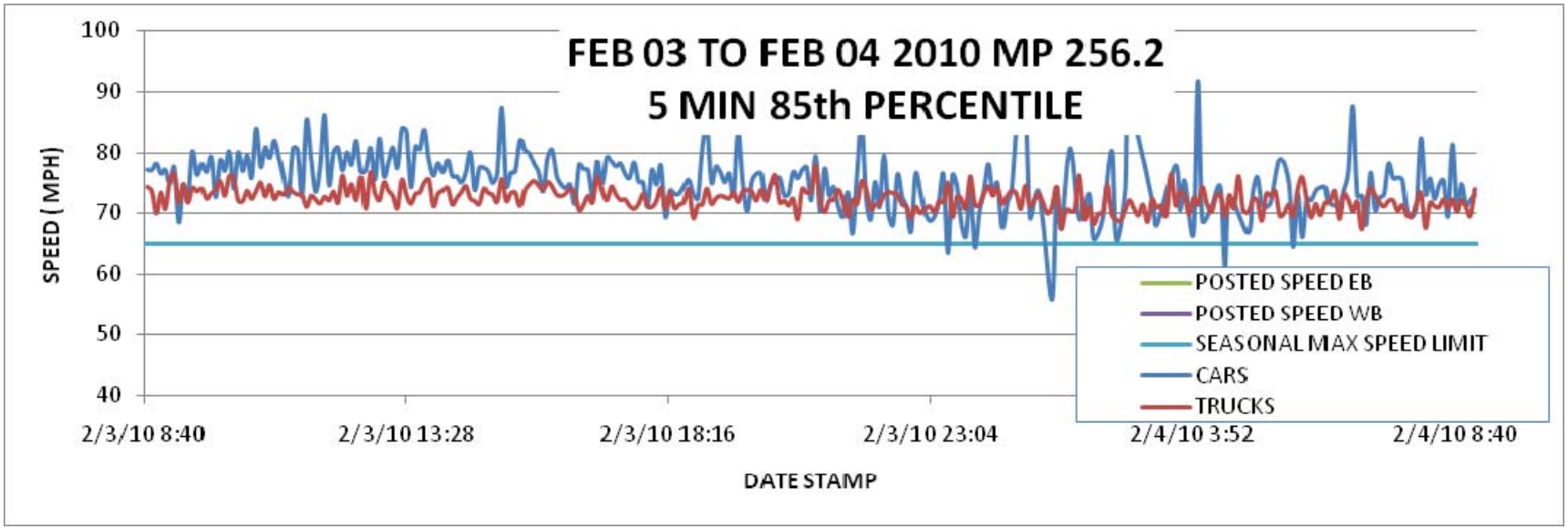
Individual Data Graphs, Charts, and Tables

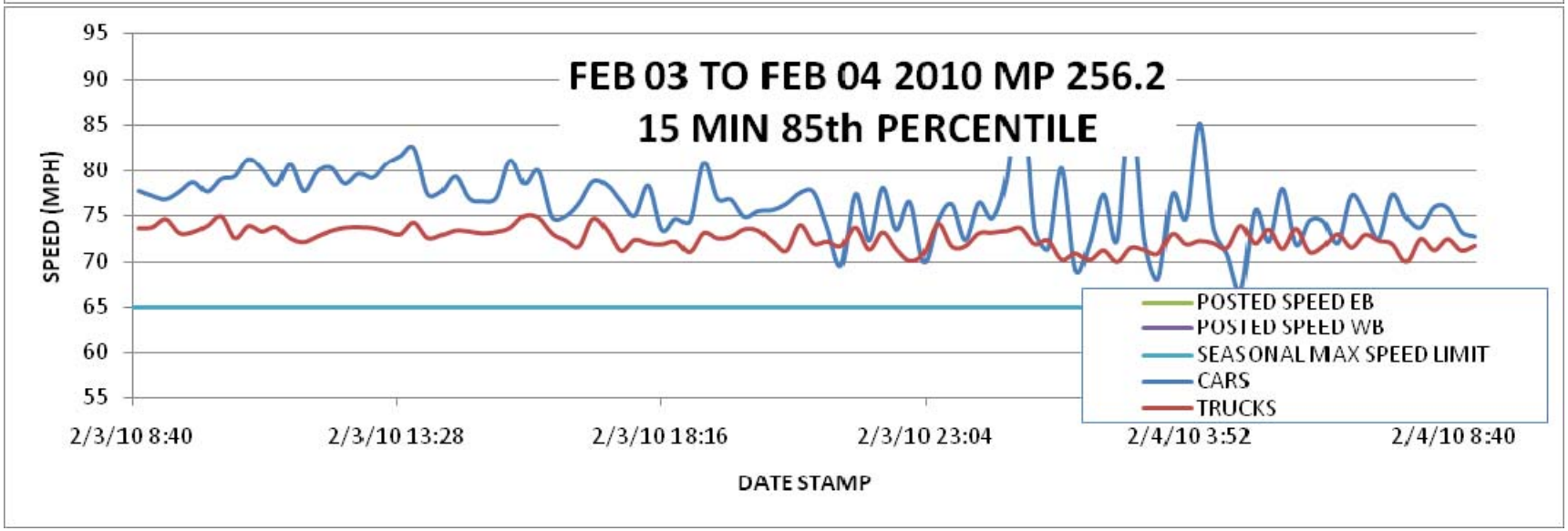

Observed Speeds MP 256.2
5 Min 85th Percentile
12/01/09 - 12/02/09
SPEED (mph)
85
75
65
55
45
35
12/1/09 15:15
12/1/09 20:03
12/2/09 0:51
12/2/09 5:39
12/2/09 10:27
12/2/09 15:15
Date and Time
POSTED SPEED EB
POSTED SPEED WB
SEASONAL MAX SPEED LIMIT
TRUCKS

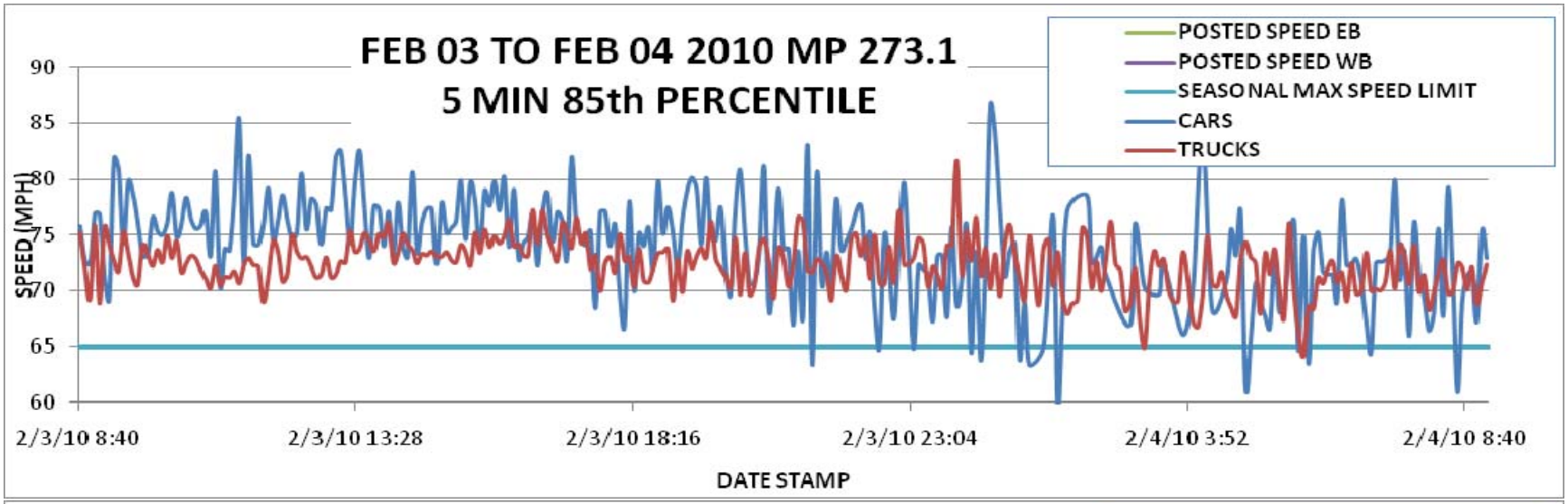

Observed Speeds MP 256.2
15 Min 85th Percentile
12/01/09 - 12/02/09
SPEED (mph)
85
75
65
55
45
35
12/1/09 15:15
12/1/09 20:03
12/2/09 0:51
12/2/09 5:39
12/2/09 10:27
12/2/09 15:15
Date and Time
POSTED SPEED EB
POSTED SPEED WB
SEASONAL MAX SPEED LIMIT
CARS
TRUCKS

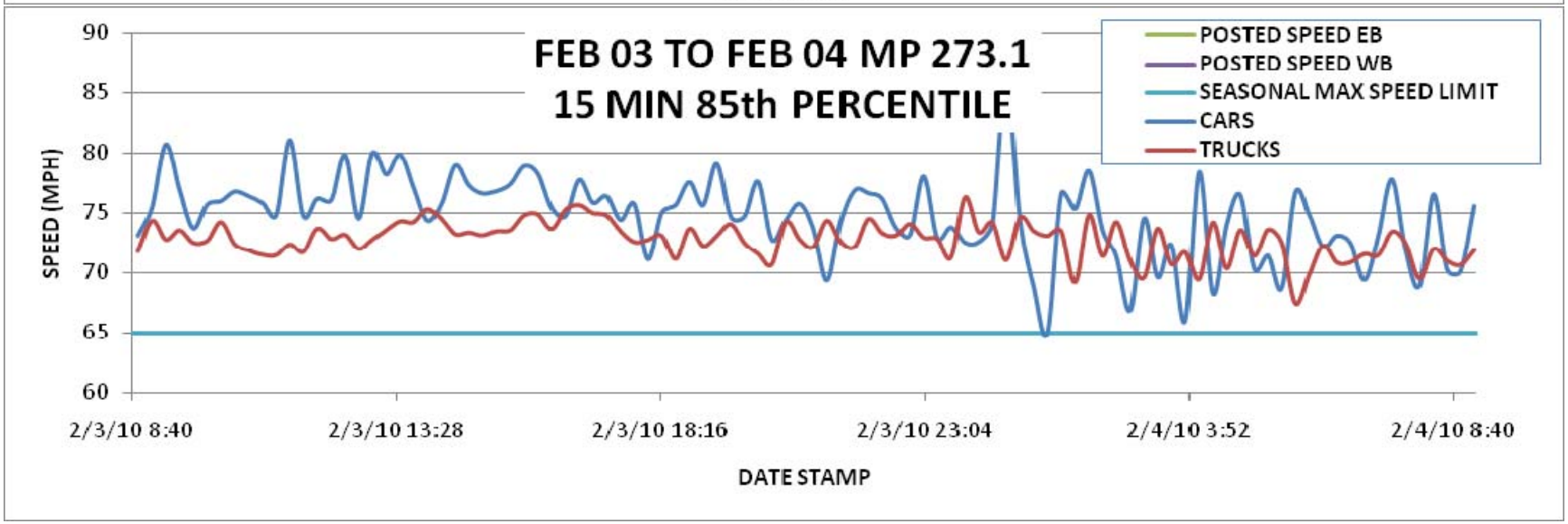

Observed Speeds MP 273.1
5 Min 85th Percentile
12/01/09 - 12/02/09
SPEED (mph)
85
80
75
70
65
60
55
50
45
40
35
12/1/2009 15:09
12/1/2009 19:57
12/2/2009 0:45
12/2/2009 5:33
12/2/2009 10:21
12/2/2009 15:09
Date and Time
POSTED SPEED EB
POSTED SPEED WB
SEASONAL MAX SPEED LIMIT
CARS
TRUCKS

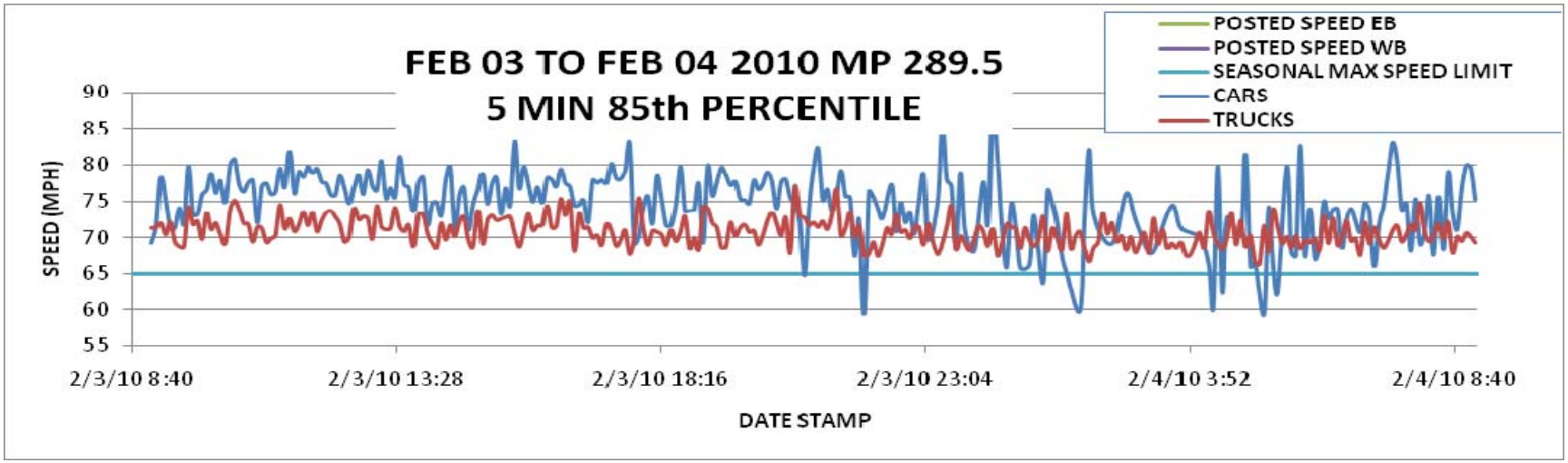

Observed Speeds MP 273.1
15 Min 85th Percentile
12/01/09 - 12/02/09
SPEED (mph)
80
75
70
65
60
55
50
45
40
35
12/1/2009 15:21
12/1/2009 20:09
12/2/2009 0:57
12/2/2009 5:45
12/2/2009 10:33
12/2/2009 15:21
Date and Time
POSTED SPEED EB
POSTED SPEED WB
SEASONAL MAX SPEED LIMIT
CARS
TRUCKS

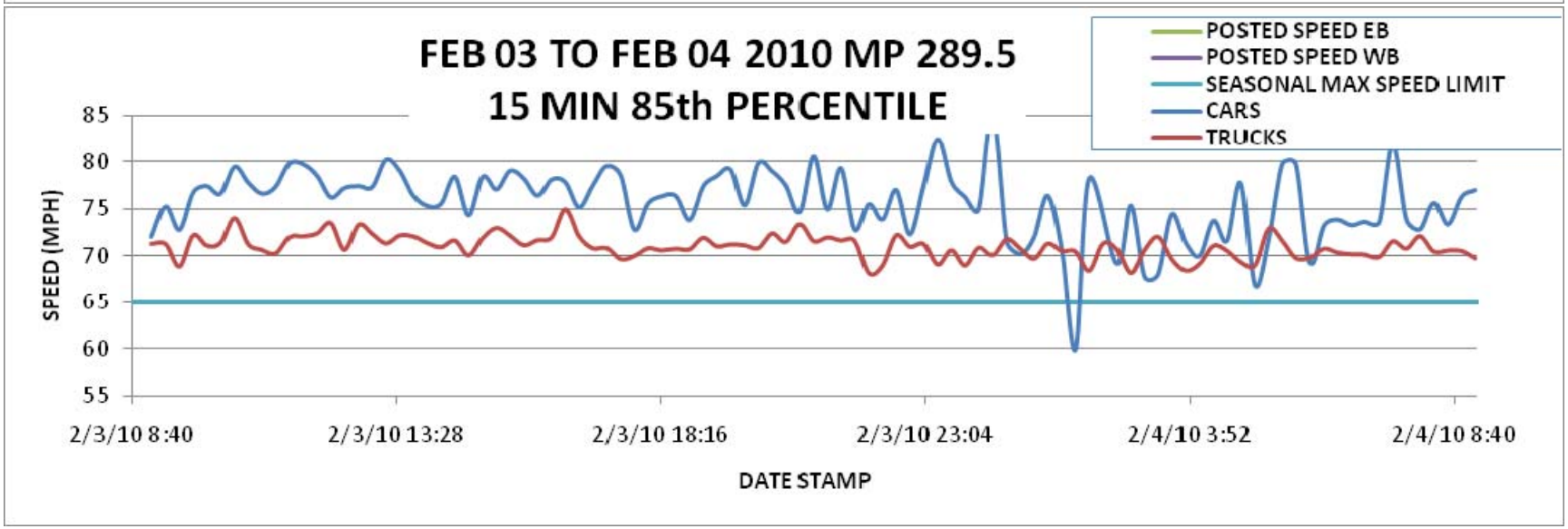

FEB 03 TO FEB 04 2010 MP 256.2
5 MIN 85th PERCENTILE
SPEED (MPH)
100
90
80
70
60
50
40
2/3/10 8:40
2/3/10 13:28
2/3/10 18:16
2/3/10 23:04
2/4/10 3:52
2/4/10 8:40
DATE STAMP
POSTED SPEED EB
POSTED SPEED WB
SEASONAL MAX SPEED LIMIT
CARS
TRUCKS

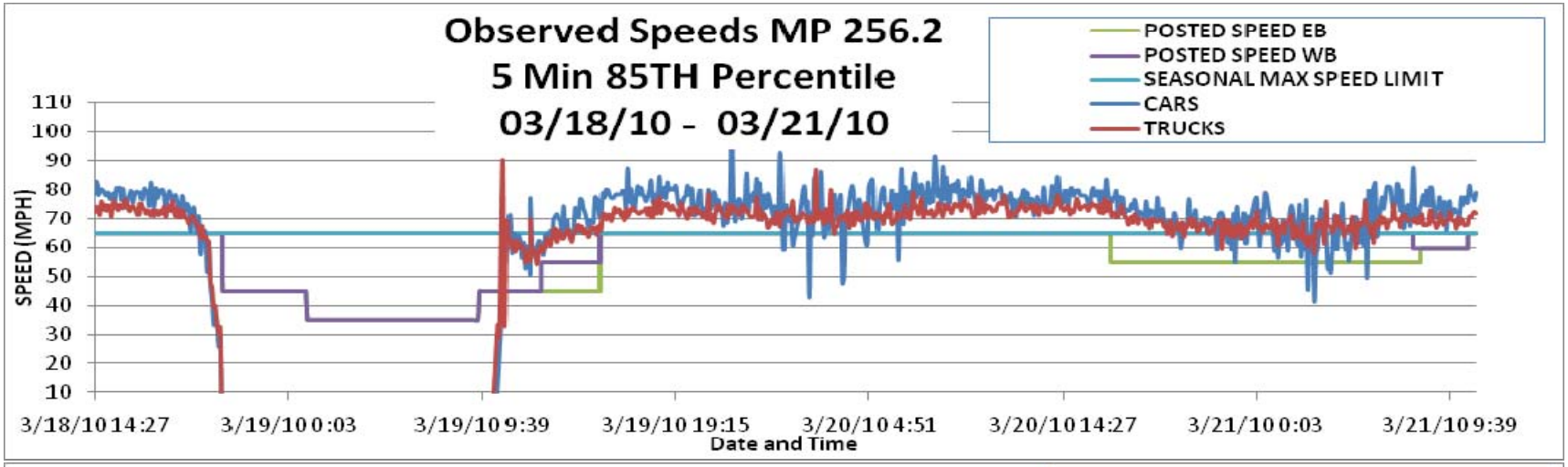

FEB 03 TO FEB 04 2010 MP 256.2
15 MIN 85th PERCENTILE
SPEED (MPH)
95
90
85
80
75
70
65
60
55
2/3/10 8:40
2/3/10 13:28
2/3/10 18:16
2/3/10 23:04
2/4/10 3:52
2/4/10 8:40
DATE STAMP
POSTED SPEED EB
POSTED SPEED WB
SEASONAL MAX SPEED LIMIT
CARS
TRUCKS

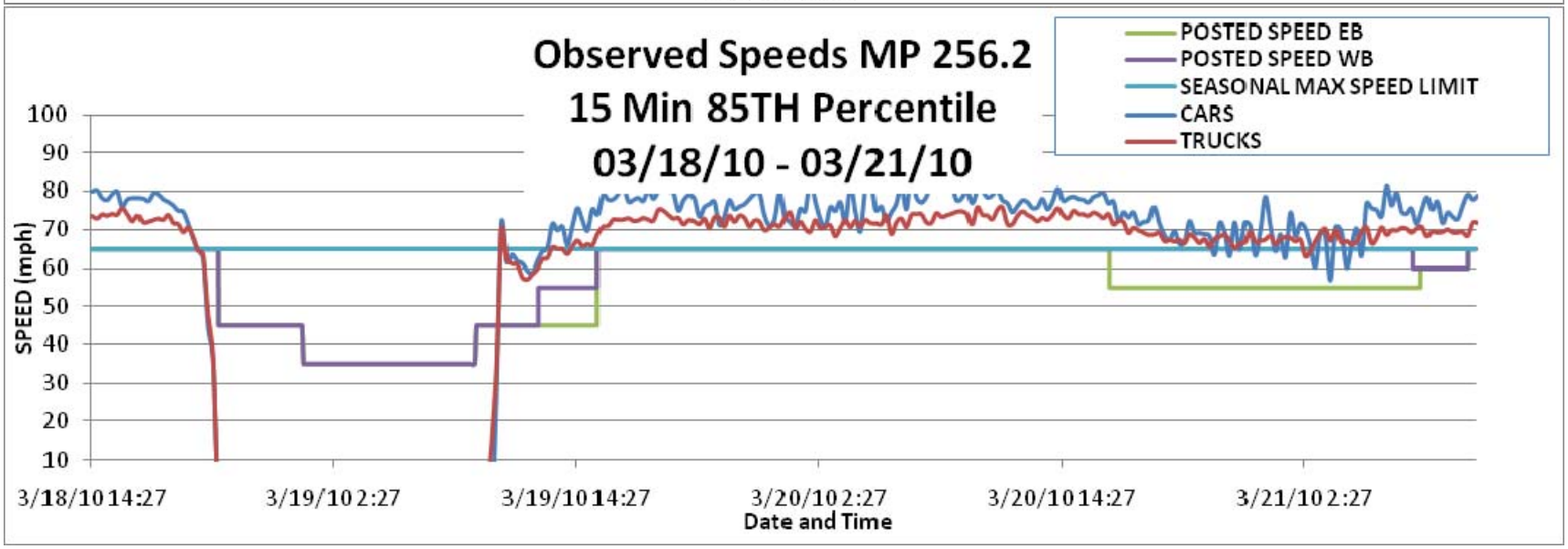

FEB 03 TO FEB 04 2010 MP 273.1
5 MIN 85th PERCENTILE
POSTED SPEED EB
POSTED SPEED WB
SEASONAL MAX SPEED LIMIT
CARS
TRUCKS
SPEED (MPH)
90
85
80
75
70
65
60
2/3/10 8:40
2/3/10 13:28
2/3/10 18:16
2/3/10 23:04
2/4/10 3:52
2/4/10 8:40
DATE STAMP

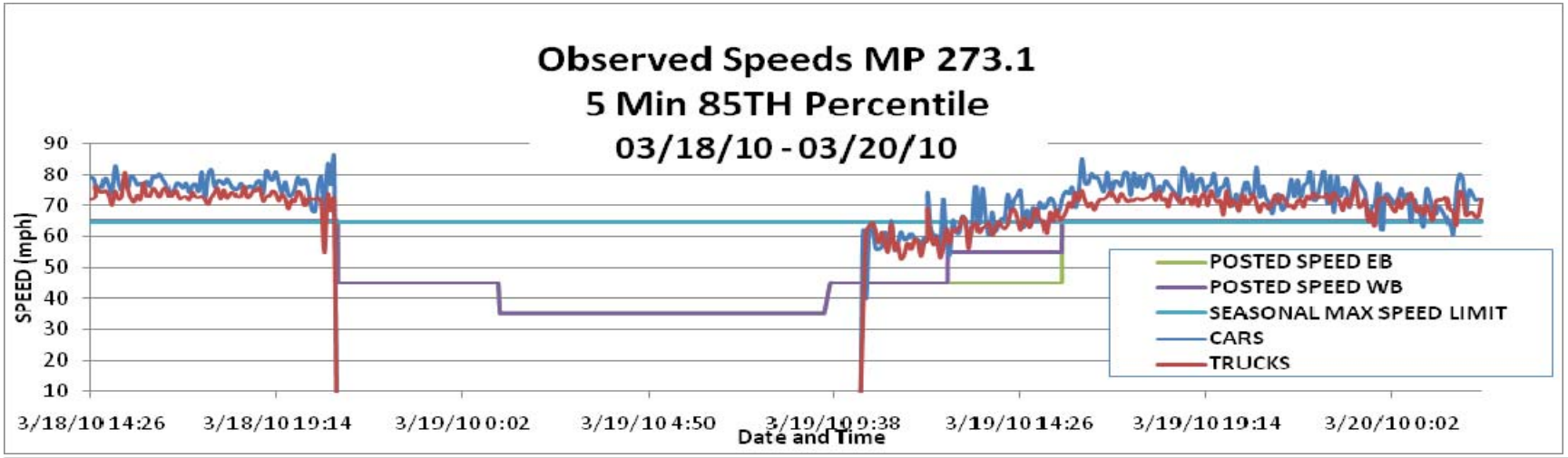

FEB 03 TO FEB 04 MP 273.1
15 MIN 85th PERCENTILE
POSTED SPEED EB
POSTED SPEED WB
SEASONAL MAX SPEED LIMIT
CARS
TRUCKS
SPEED (MPH)
90
85
80
75
70
65
60
2/3/10 8:40
2/3/10 13:28
2/3/10 18:16
2/3/10 23:04
2/4/10 3:52
2/4/10 8:40
DATE STAMP

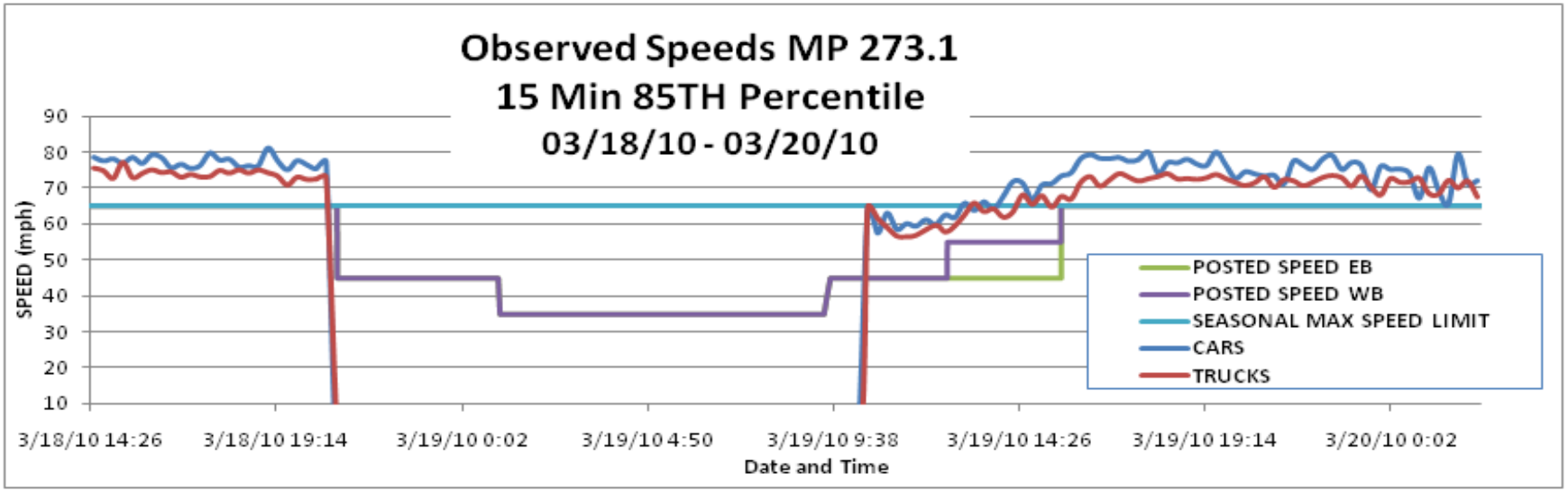

FEB 03 TO FEB 04 2010 MP 289.5
5 MIN 85th PERCENTILE
POSTED SPEED EB
POSTED SPEED WB
SEASONAL MAX SPEED LIMIT
CARS
TRUCKS
SPEED (MPH)
90
85
80
75
70
65
60
55
2/3/10 8:40
2/3/10 13:28
2/3/10 18:16
2/3/10 23:04
2/4/10 3:52
2/4/10 8:40
DATE STAMP

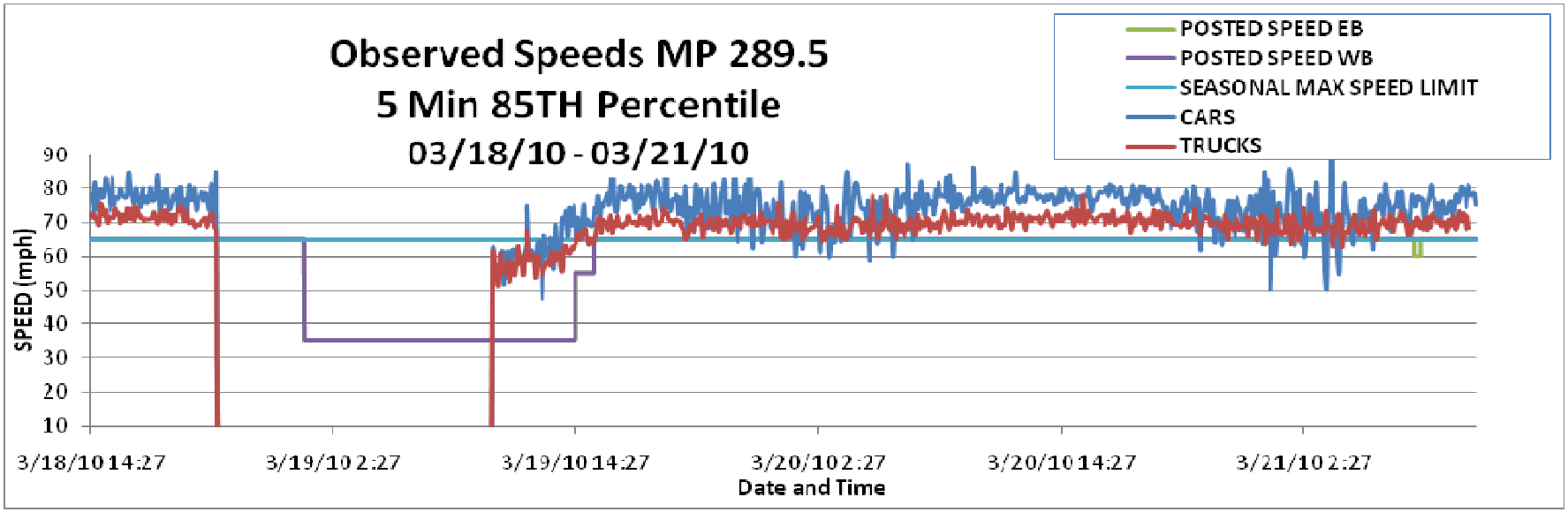

FEB 03 TO FEB 04 2010 MP 289.5
15 MIN 85th PERCENTILE
POSTED SPEED EB
POSTED SPEED WB
SEASONAL MAX SPEED LIMIT
CARS
TRUCKS
SPEED (MPH)
85
80
75
70
65
60
55
2/3/10 8:40
2/3/10 13:28
2/3/10 18:16
2/3/10 23:04
2/4/10 3:52
2/4/10 8:40
DATE STAMP

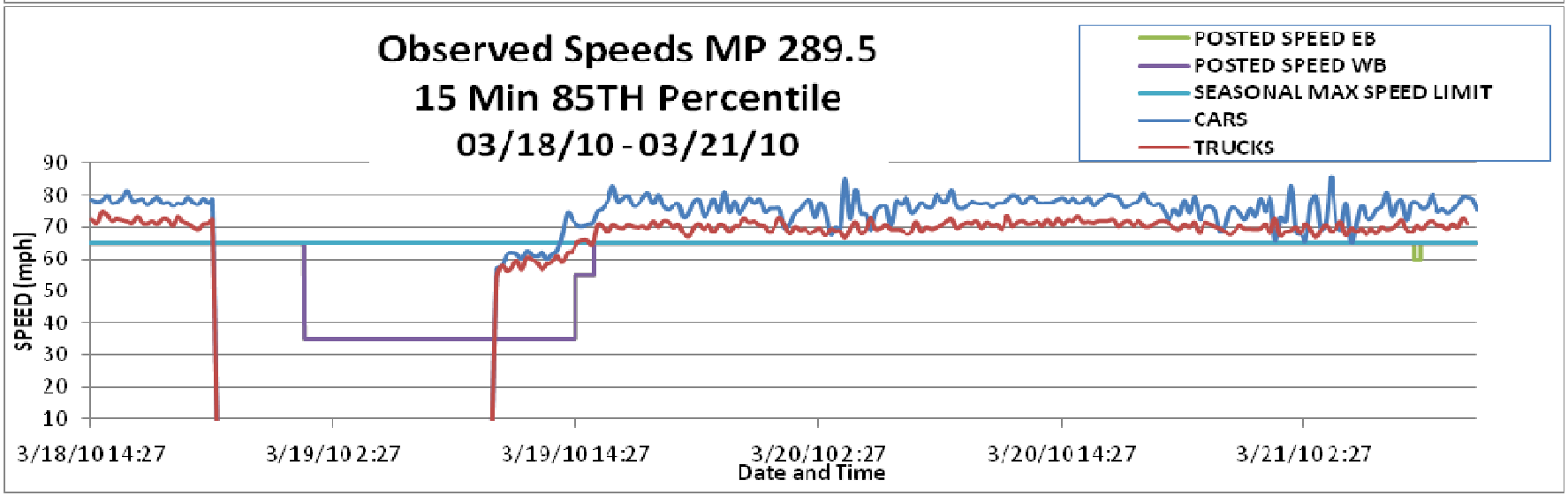

Observed Speeds MP 256.2
5 Min 85TH Percentile
03/18/10 - 03/21/10
POSTED SPEED EB
POSTED SPEED WB
SEASONAL MAX SPEED LIMIT
CARS
TRUCKS
SPEED (MPH)
110
100
90
80
70
60
50
40
30
20
10
3/18/10 14:27
3/19/10 0:03
3/19/10 9:39
3/19/10 19:15
3/20/10 4:51
3/20/10 14:27
3/21/10 0:03
3/21/10 9:39
Date and Time

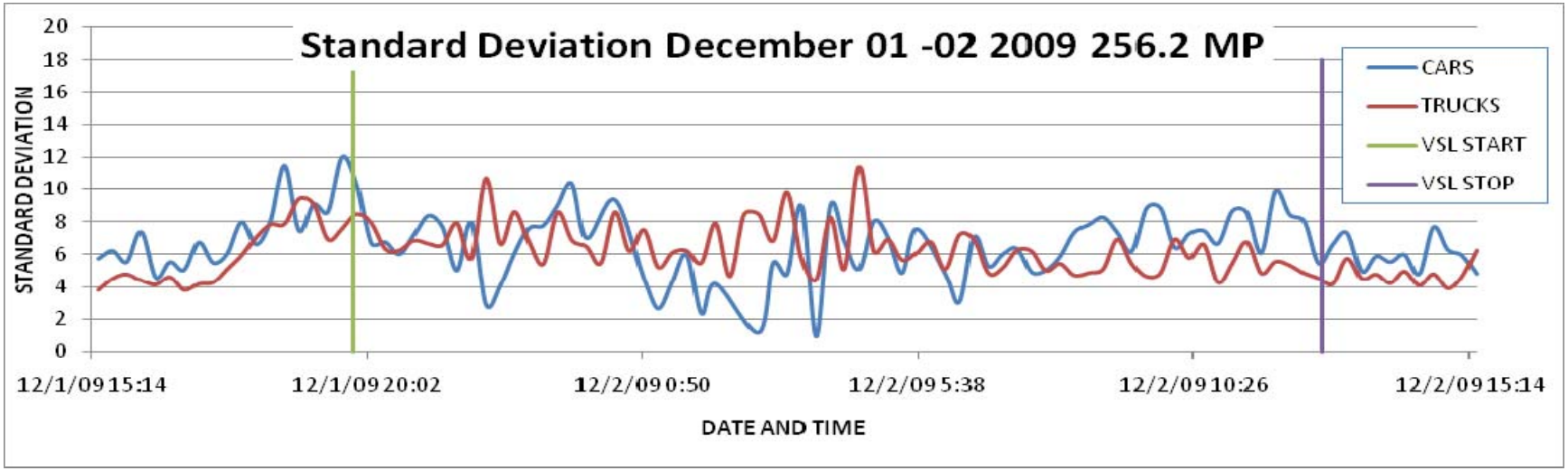

Observed Speeds MP 256.2
15 Min 85TH Percentile
03/18/10 - 03/21/10
POSTED SPEED EB
POSTED SPEED WB
SEASONAL MAX SPEED LIMIT
CARS
TRUCKS
SPEED (mph)
100
90
80
70
60
50
40
30
20
10
3/18/10 14:27
3/19/10 2:27
3/19/10 14:27
3/20/10 2:27
3/20/10 14:27
3/21/10 2:27
Date and Time

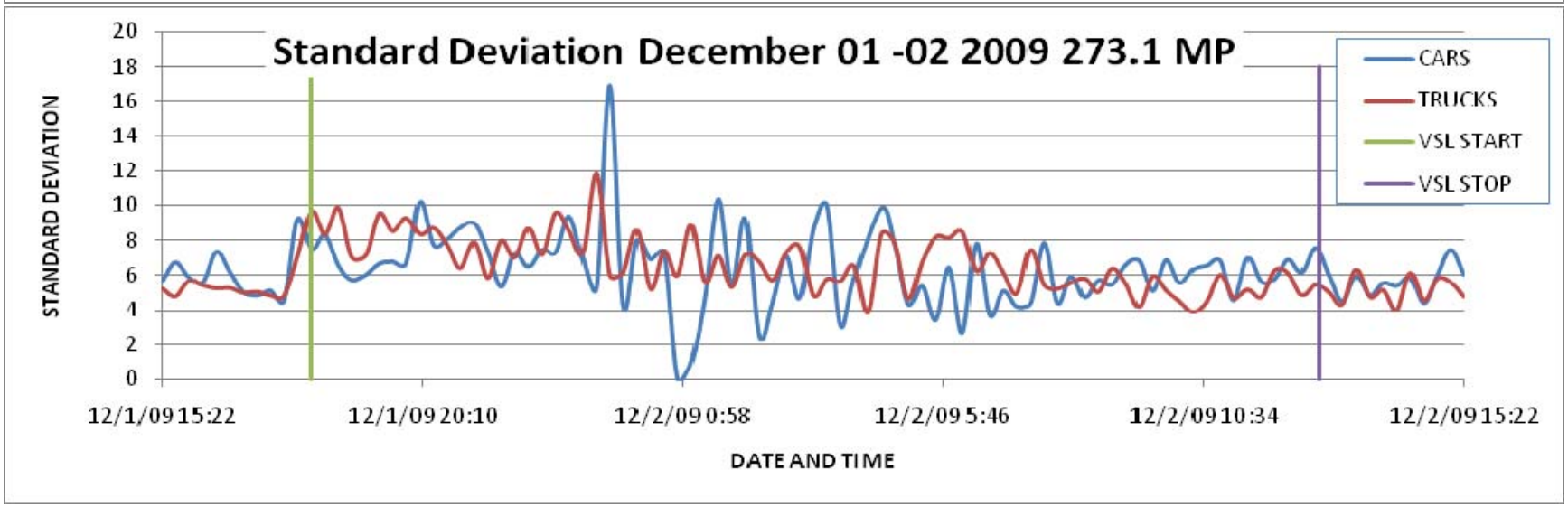

Observed Speeds MP 273.1
5 Min 85TH Percentile
03/18/10 - 03/20/10
SPEED (mph)
90
80
70
60
50
40
30
20
10
3/18/10 14:26
3/18/10 19:14
3/19/10 0:02
3/19/10 4:50
3/19/10 9:38
3/19/10 14:26
3/19/10 19:14
3/20/10 0:02
Date and Time
POSTED SPEED EB
POSTED SPEED WB
SEASONAL MAX SPEED LIMIT
CARS
TRUCKS

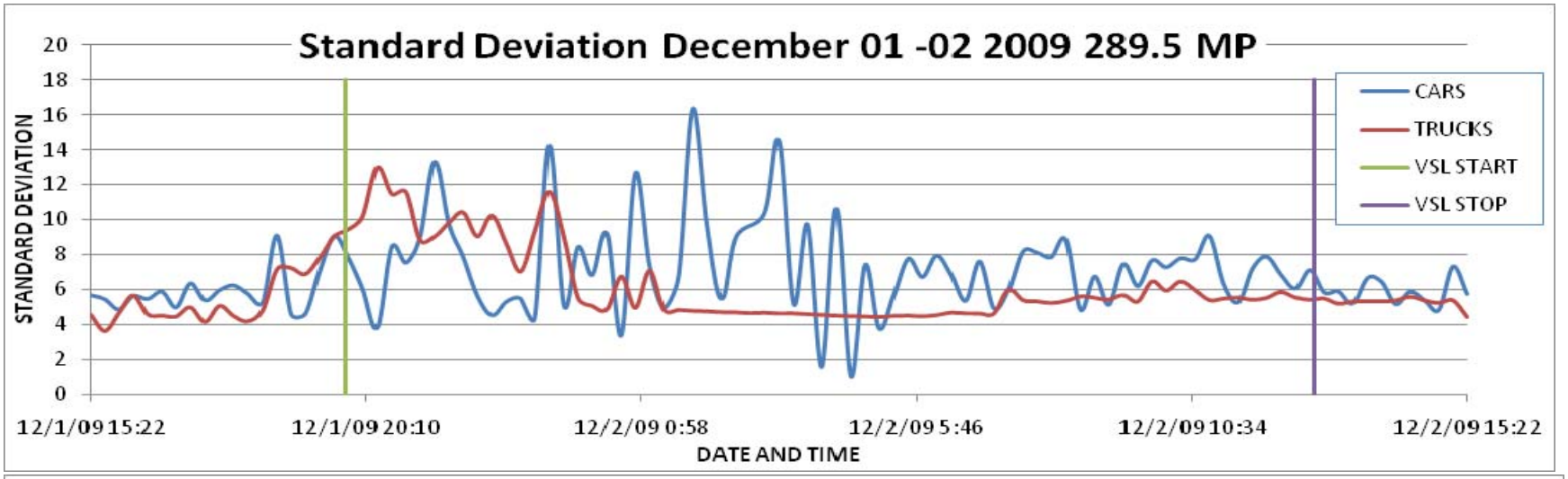

Observed Speeds MP 273.1
15 Min 85TH Percentile
03/18/10 - 03/20/10
SPEED (mph)
90
80
70
60
50
40
30
20
10
3/18/10 14:26
3/18/10 19:14
3/19/10 0:02
3/19/10 4:50
3/19/10 9:38
3/19/10 14:26
3/19/10 19:14
3/20/10 0:02
Date and Time
POSTED SPEED EB
POSTED SPEED WB
SEASONAL MAX SPEED LIMIT
CARS
TRUCKS

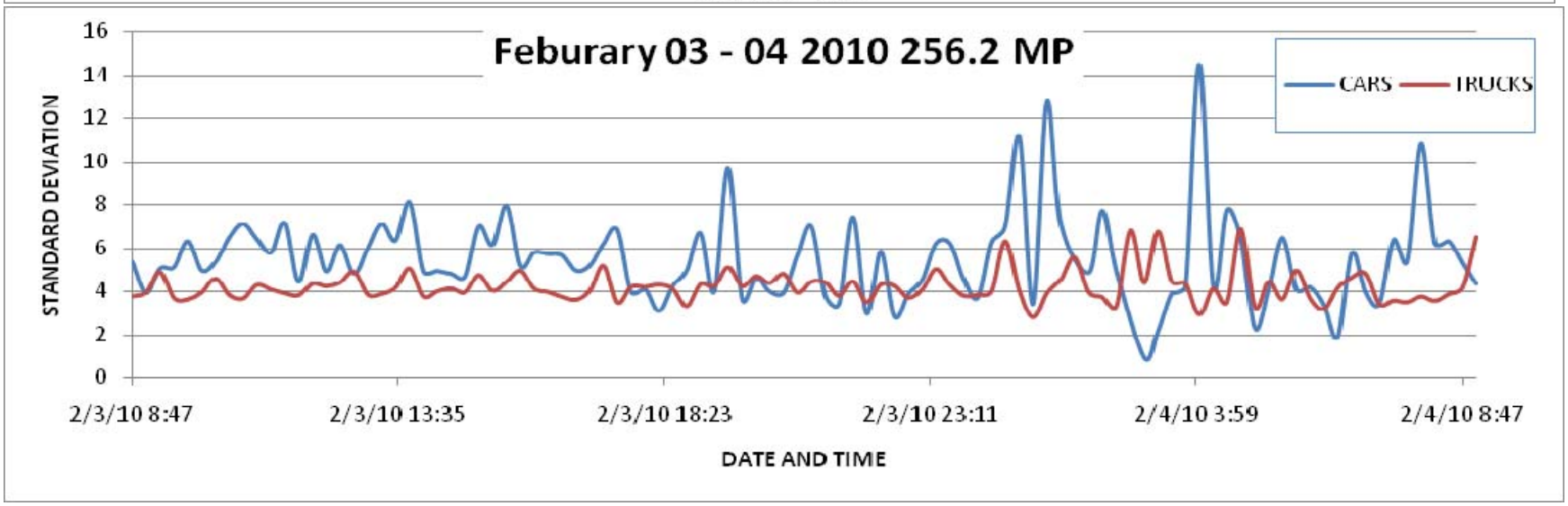

Observed Speeds MP 289.5
5 Min 85TH Percentile
03/18/10 - 03/21/10
POSTED SPEED EB
POSTED SPEED WB
SEASONAL MAX SPEED LIMIT
CARS
TRUCKS
SPEED (mph)
90
80
70
60
50
40
30
20
10
3/18/10 14:27
3/19/10 2:27
3/19/10 14:27
3/20/10 2:27
3/20/10 14:27
3/21/10 2:27
Date and Time

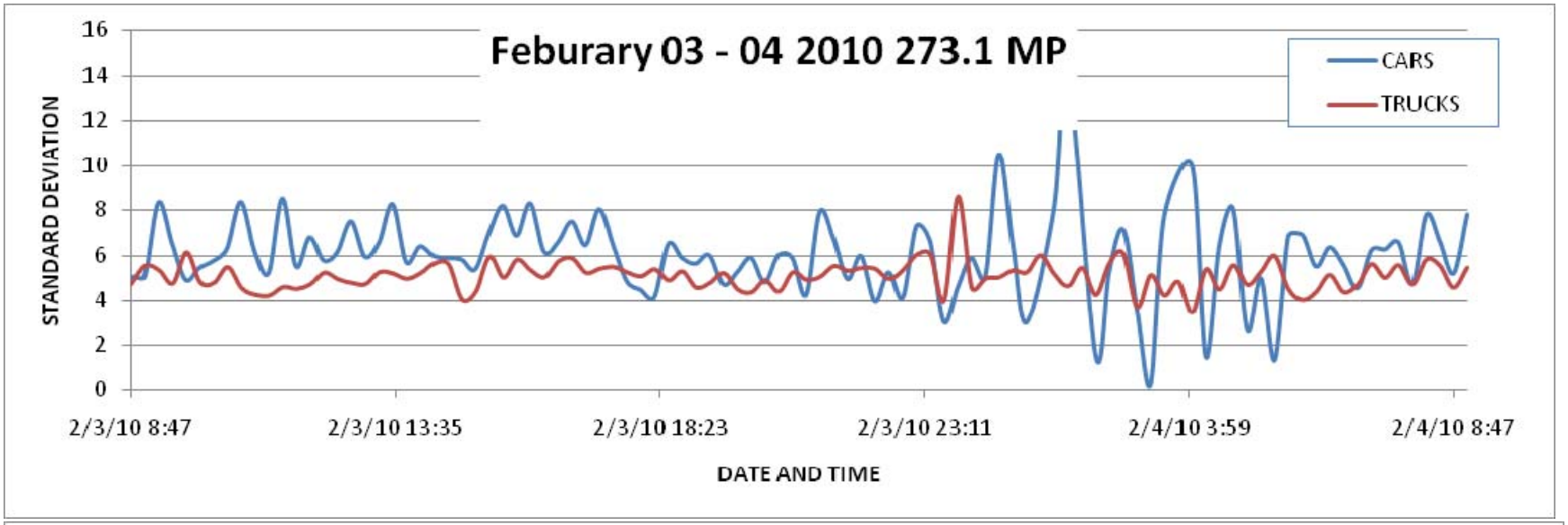

Observed Speeds MP 289.5
15 Min 85TH Percentile
03/18/10 - 03/21/10
POSTED SPEED EB
POSTED SPEED WB
SEASONAL MAX SPEED LIMIT
CARS
TRUCKS
SPEED (mph)
90
80
70
60
50
40
30
20
10
3/18/10 14:27
3/19/10 2:27
3/19/10 14:27
3/20/10 2:27
3/20/10 14:27
3/21/10 2:27
Date and Time

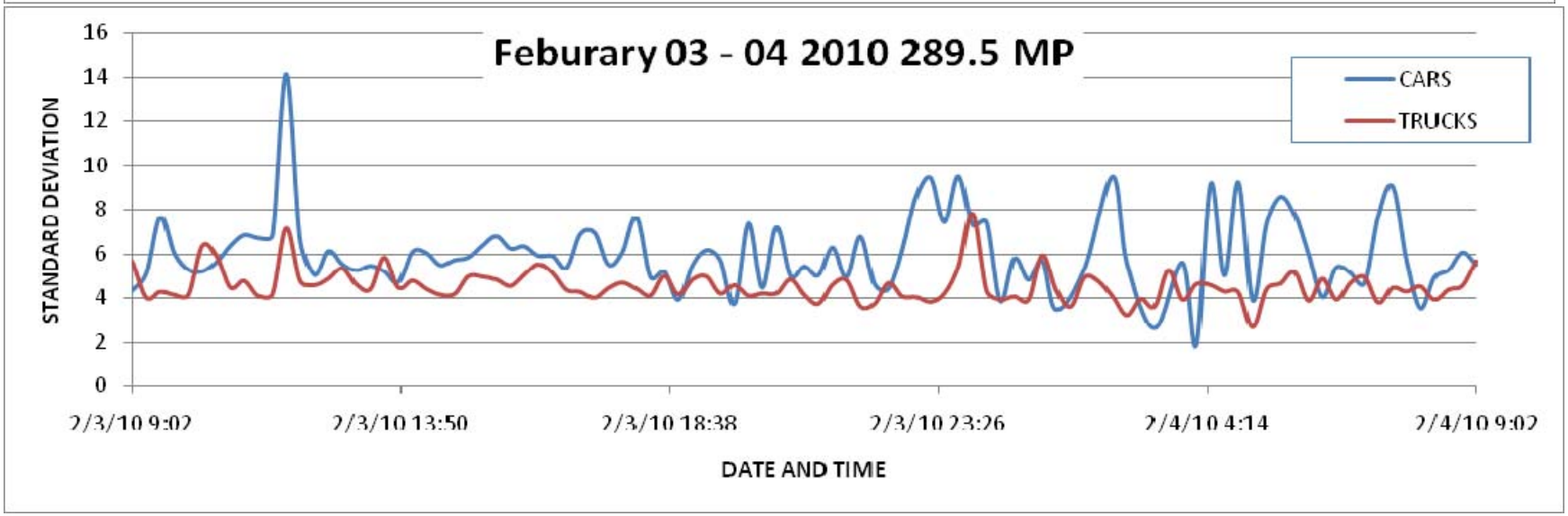

Standard Deviation December 01 -02 2009 256.2 MP
STANDARD DEVIATION
20
18
16
14
12
10
8
6
4
2
0
12/1/09 15:14
12/1/09 20:02
12/2/09 0:50
12/2/09 5:38
12/2/09 10:26
12/2/09 15:14
DATE AND TIME
CARS
TRUCKS
VSL START
VSL STOP

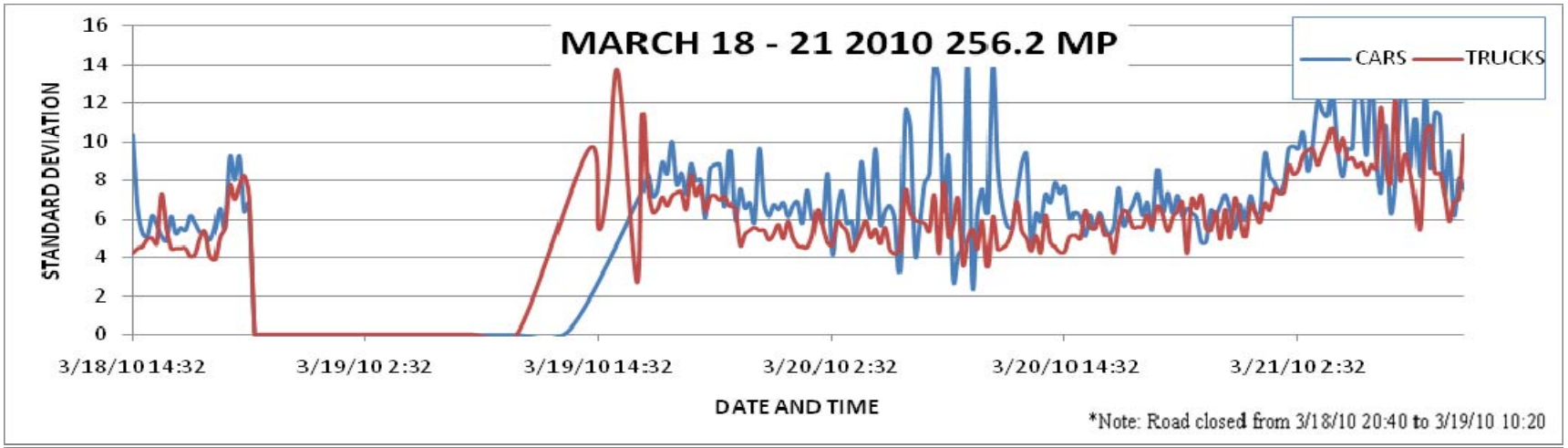

Standard Deviation December 01 -02 2009 273.1 MP
STANDARD DEVIATION
20
18
16
14
12
10
8
6
4
2
0
12/1/09 15:22
12/1/09 20:10
12/2/09 0:58
12/2/09 5:46
12/2/09 10:34
12/2/09 15:22
DATE AND TIME
CARS
TRUCKS
VSL START
VSL STOP

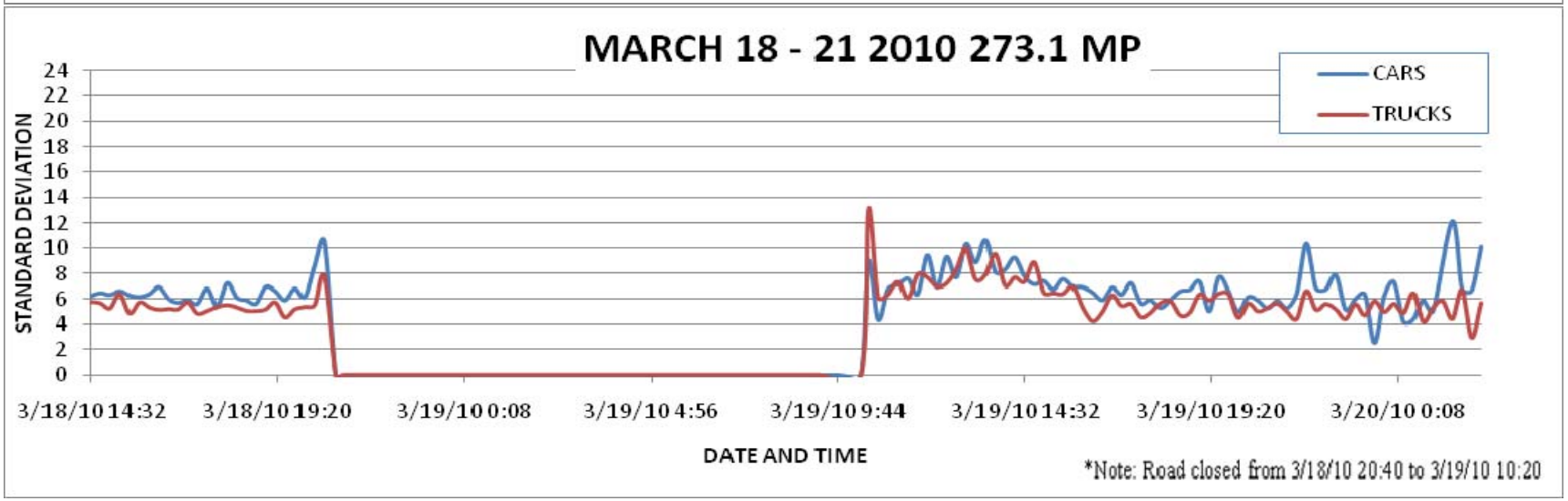

Standard Deviation December 01 -02 2009 289.5 MP
STANDARD DEVIATION
20
18
16
14
12
10
8
6
4
2
0
12/1/09 15:22
12/1/09 20:10
12/2/09 0:58
12/2/09 5:46
12/2/09 10:34
12/2/09 15:22
DATE AND TIME
CARS
TRUCKS
VSL START
VSL STOP


Feburary 03 - 04 2010 256.2 MP
STANDARD DEVIATION
16
14
12
10
8
6
4
2
0
2/3/10 8:47
2/3/10 13:35
2/3/10 18:23
2/3/10 23:11
2/4/10 3:59
2/4/10 8:47
DATE AND TIME
CARS
TRUCKS


Feburary 03 - 04 2010 273.1 MP
CARS
TRUCKS
STANDARD DEVIATION
16
14
12
10
8
6
4
2
0
2/3/10 8:47
2/3/10 13:35
2/3/10 18:23
2/3/10 23:11
2/4/10 3:59
2/4/10 8:47
DATE AND TIME


Feburary 03 - 04 2010 289.5 MP
CARS
TRUCKS
STANDARD DEVIATION
16
14
12
10
8
6
4
2
0
2/3/10 9:02
2/3/10 13:50
2/3/10 18:38
2/3/10 23:26
2/4/10 4:14
2/4/10 9:02
DATE AND TIME


MARCH 18 - 21 2010 256.2 MP
CARS
TRUCKS
STANDARD DEVIATION
16
14
12
10
8
6
4
2
0
3/18/10 14:32
3/19/10 2:32
3/19/10 14:32
3/20/10 2:32
3/20/10 14:32
3/21/10 2:32
DATE AND TIME
*Note: Road closed from 3/18/10 20:40 to 3/19/10 10:20


MARCH 18 - 21 2010 273.1 MP
CARS
TRUCKS
STANDARD DEVIATION
24
22
20
18
16
14
12
10
8
6
4
2
0
3/18/10 14:32
3/18/10 19:20
3/19/10 0:08
3/19/10 4:56
3/19/10 9:44
3/19/10 14:32
3/19/10 19:20
3/20/10 0:08
DATE AND TIME
*Note: Road closed from 3/18/10 20:40 to 3/19/10 10:20

December 1-2, 2009 Milepost 256.5

CARS	IDEAL	TRANSITION	VSL IMPLEMENTED	EXTENDED VSL
DURATION	12/1/2009 3:14:52 PM TO 12/1/2009 5:43:36 PM	12/1/2009 5:44:57 PM TO 12/1/2009 7:49:49 PM	12/1/2009 7:50:51 PM TO 12/2/2009 2:12:48 AM	12/2/2009 2:29:59 AM TO 12/2/2009 12:41:56 PM
# OBSERVATIONS	384	166	191	710
AVG SPEED	72.27	56.24	57.27	66.78
85th % SPEED	78.46	68.06	64.45	74.87
STD DEVIATION	5.98	11.67	7.70	7.59

TRUCKS	IDEAL	TRANSITION	VSL IMPLEMENTED	EXTENDED VSL
DURATION	12/1/2009 3:14:52 PM TO 12/1/2009 5:43:36 PM	12/1/2009 5:44:57 PM TO 12/1/2009 7:49:49 PM	12/1/2009 7:50:51 PM TO 12/2/2009 2:12:48 AM	12/2/2009 2:29:59 AM TO 12/2/2009 12:41:56 PM
# OBSERVATIONS	983	677	1205	2843
AVG SPEED	68.85	56.04	57.77	62.88
85th % SPEED	73.17	66.21	64.30	68.40
STD DEVIATION	4.40	9.51	7.48	6.00

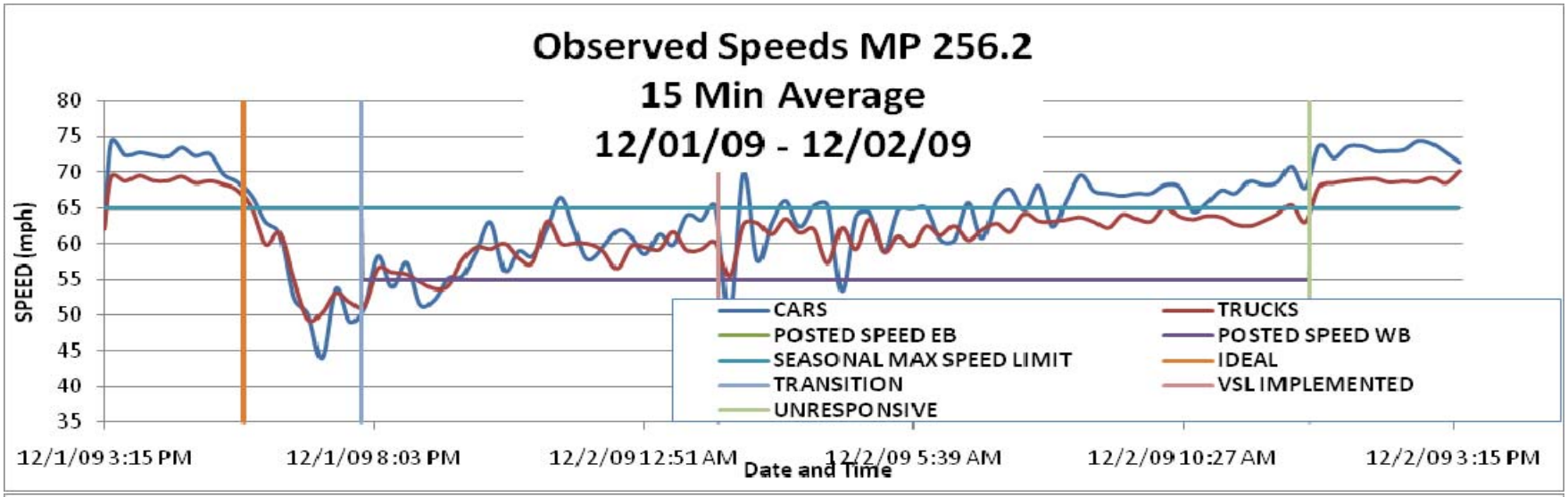
Calculations based on 15 minute Average Speeds

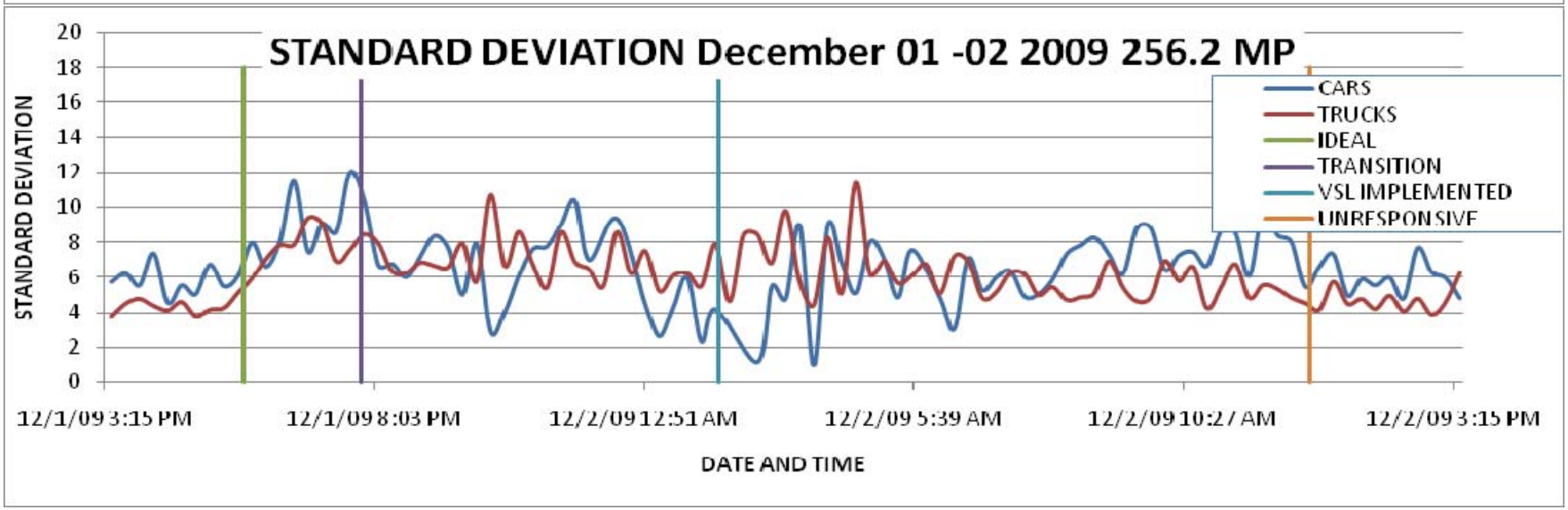
December 1-2, 2009 MILEPOST 273.1

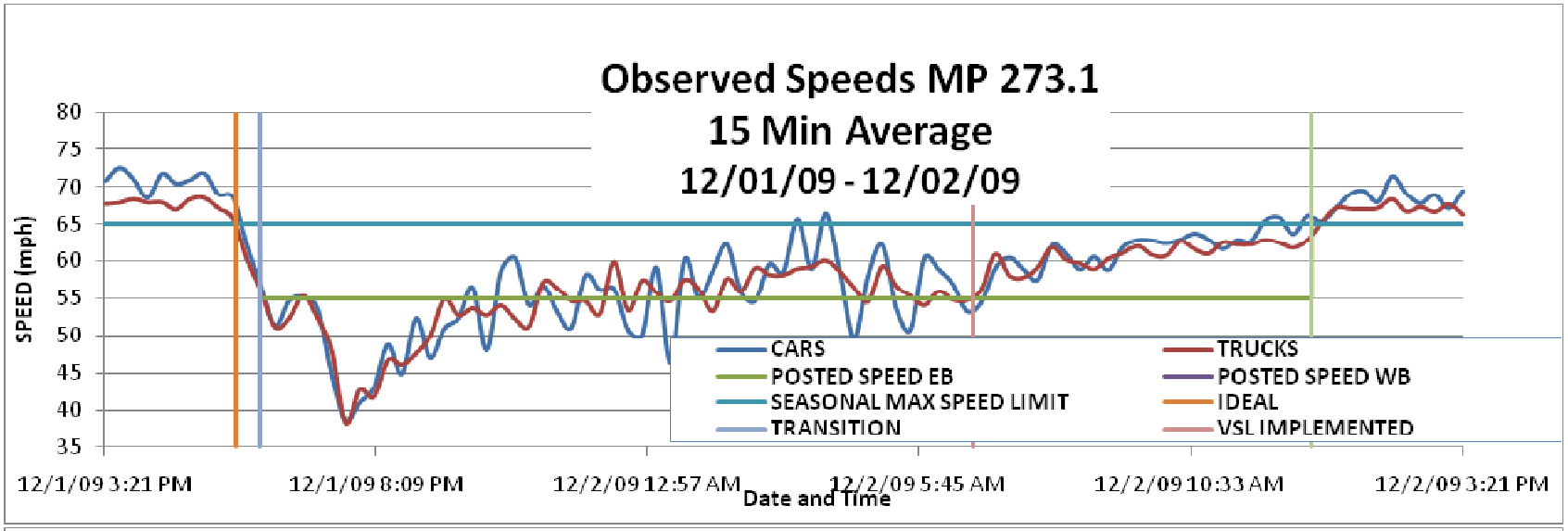
CARS	IDEAL	TRANSITION	VSL IMPLEMENTED	EXTENDED VSL
DURATION	12/1/2009 3:16:03 PM TO 12/1/2009 5:40:56 PM	12/1/2009 5:41:03 PM TO 12/1/2009 6:06:26 PM	12/1/2009 6:06:15 PM TO 12/2/2009 6:45:05 AM	12/2/2009 6:45:05 AM TO 12/2/2009 12:41:51 PM
# OBSERVATIONS	410	50	476	726
AVG SPEED	70.71	7.14	52.18	62.05
85th % SPEED	77.13	70.55	61.63	68.50
STD DEVIATION	5.88	8.65	9.20	6.54

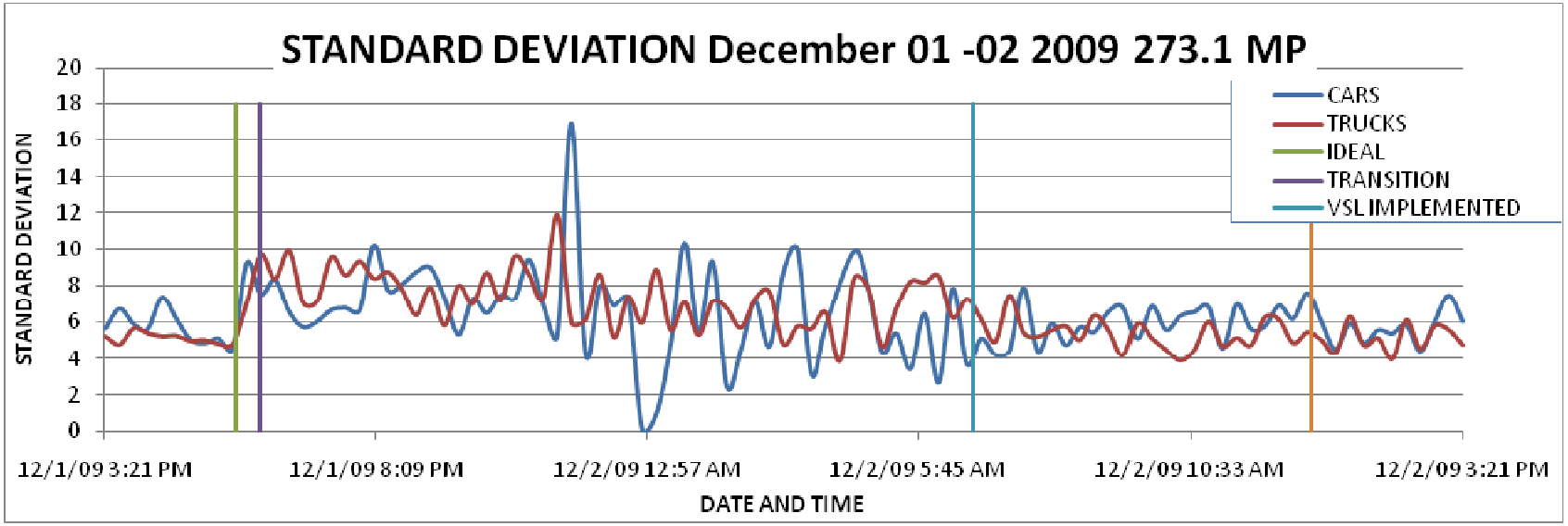
TRUCKS	IDEAL	TRANSITION	VSL IMPLEMENTED	EXTENDED VSL
DURATION	12/1/2009 3:16:03 PM TO 12/1/2009 5:25:56 PM	12/1/2009 5:26:03 PM TO 12/1/2009 6:06:26 PM	12/1/2009 6:06:15 PM TO 12/2/2009 6:45:05 AM	12/2/2009 6:45:05 AM TO 12/2/2009 12:41:51 PM
# OBSERVATIONS	921	156	2407	2142
AVG SPEED	67.71	59.36	52.92	61.02
85th % SPEED	73.10	67.25	61.60	66.30
STD DEVIATION	5.17	8.32	9.18	5.60

Calculations based on 15 minute Average Speeds


Observed Speeds MP 256.2
15 Min Average
12/01/09 - 12/02/09
SPEED (mph)
80
75
70
65
60
55
50
45
40
35
CARS
TRUCKS
POSTED SPEED EB
POSTED SPEED WB
SEASONAL MAX SPEED LIMIT
IDEAL
TRANSITION
VSL IMPLEMENTED
UNRESPONSIVE
12/1/09 3:15 PM
12/1/09 8:03 PM
12/2/09 12:51 AM
12/2/09 5:39 AM
12/2/09 10:27 AM
12/2/09 3:15 PM
Date and Time


STANDARD DEVIATION December 01 -02 2009 256.2 MP
STANDARD DEVIATION
20
18
16
14
12
10
8
6
4
2
0
CARS
TRUCKS
IDEAL
TRANSITION
VSL IMPLEMENTED
UNRESPONSIVE
12/1/09 3:15 PM
12/1/09 8:03 PM
12/2/09 12:51 AM
12/2/09 5:39 AM
12/2/09 10:27 AM
12/2/09 3:15 PM
DATE AND TIME


Observed Speeds MP 273.1
15 Min Average
12/01/09 - 12/02/09
SPEED (mph)
80
75
70
65
60
55
50
45
40
35
12/1/09 3:21 PM
12/1/09 8:09 PM
12/2/09 12:57 AM
12/2/09 5:45 AM
12/2/09 10:33 AM
12/2/09 3:21 PM
Date and Time
CARS
TRUCKS
POSTED SPEED EB
POSTED SPEED WB
SEASONAL MAX SPEED LIMIT
IDEAL
TRANSITION
VSL IMPLEMENTED


STANDARD DEVIATION December 01 -02 2009 273.1 MP
STANDARD DEVIATION
20
18
16
14
12
10
8
6
4
2
0
12/1/09 3:21 PM
12/1/09 8:09 PM
12/2/09 12:57 AM
12/2/09 5:45 AM
12/2/09 10:33 AM
12/2/09 3:21 PM
DATE AND TIME
CARS
TRUCKS
IDEAL
TRANSITION
VSL IMPLEMENTED

March 18-21, 2010 MILEPOST 256.2

CARS	IDEAL	TRANSITION	VSL IMPLEMENTED	EXTENDED VSL
DURATION	3/18/2010 2:29:02 PM TO 3/18/2010 6:55:26 PM	3/18/2010 6:55:26 PM TO 3/18/2010 8:49:26 PM	3/18/2010 8:49:26 PM TO 3/19/2010 10:08:26 AM	3/19/2010 10:08:26 AM TO 3/19/2010 3:31:21 PM
# OBSERVATIONS	1089	197	N/A	976
AVG SPEED	73.15	50.07	N/A	59.10
85th % SPEED	74.21	65.71	N/A	64.06
STD DEVIATION	1.14	15.87	N/A	5.47

TRUCKS	IDEAL	TRANSITION	VSL IMPLEMENTED	EXTENDED VSL
DURATION	3/18/2010 2:29:02 PM TO 3/18/2010 6:55:26 PM	3/18/2010 6:55:26 PM TO 3/18/2010 8:49:26 PM	3/18/2010 8:49:26 PM TO 3/19/2010 10:08:26 AM	3/19/2010 10:08:26 AM TO 3/19/2010 3:31:21 PM
# OBSERVATIONS	1640	480	N/A	2946
AVG SPEED	68.90	49.76	N/A	55.07
85th % SPEED	69.44	64.34	N/A	59.51
STD DEVIATION	0.59	15.49	N/A	6.49

Calculations based on 15 minute Average Speeds

March 18-21, 2010 MILEPOST 273.1

CARS	IDEAL	TRANSITION	VSL IMPLEMENTED	EXTENDED VSL
DURATION	3/18/2010 2:26:27 PM TO 3/18/2010 8:15:26 PM	3/18/2010 8:15:26 PM TO 3/18/2010 8:49:26 PM	3/18/2010 8:49:26 PM TO 3/19/2010 10:15:26 AM	3/19/2010 10:15:26 AM TO 3/19/2010 3:31:21 PM
# OBSERVATIONS	1435	48	N/A	1096
AVG SPEED	71.66	66.56	N/A	56.54
85th % SPEED	72.61	66.66	N/A	62.71
STD DEVIATION	1.01	0.14	N/A	5.10

TRUCKS	IDEAL	TRANSITION	VSL IMPLEMENTED	EXTENDED VSL
DURATION	3/18/2010 2:26:27 PM TO 3/18/2010 8:15:26 PM	3/18/2010 8:15:26 PM TO 3/18/2010 8:49:26 PM	3/18/2010 8:49:26 PM TO 3/19/2010 10:15:26 AM	3/19/2010 10:15:26 AM TO 3/19/2010 3:31:21 PM
# OBSERVATIONS	2004	81	N/A	2844
AVG SPEED	68.29	65.53	N/A	53.15
85th % SPEED	68.99	66.81	N/A	58.07
STD DEVIATION	0.85	1.82	N/A	7.14

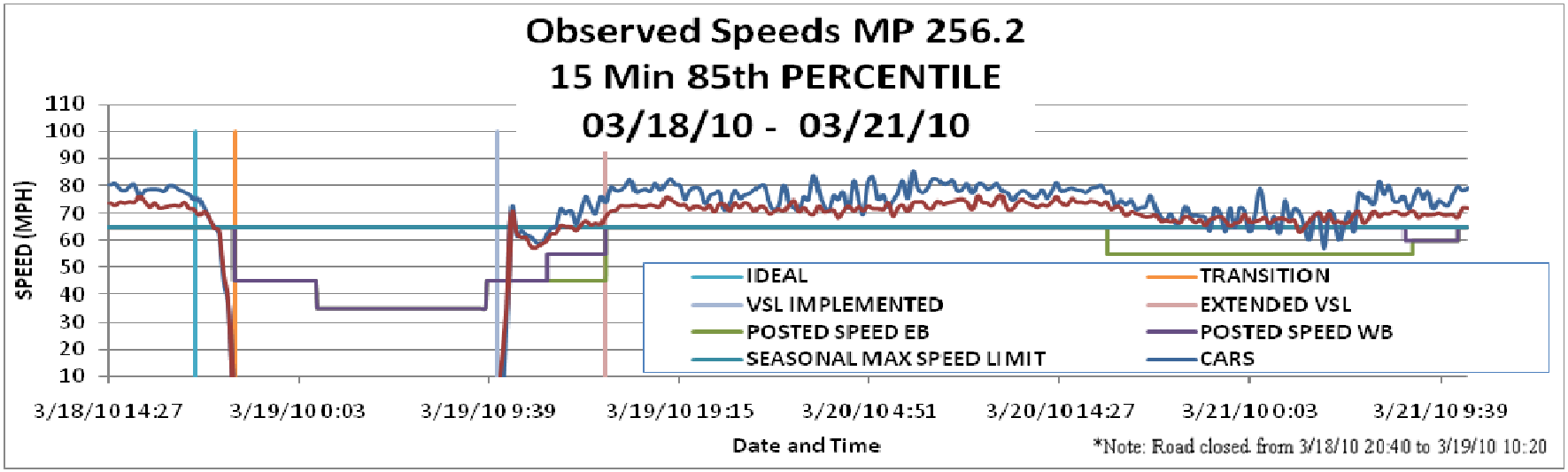
Calculations based on 15 minute Average Speeds

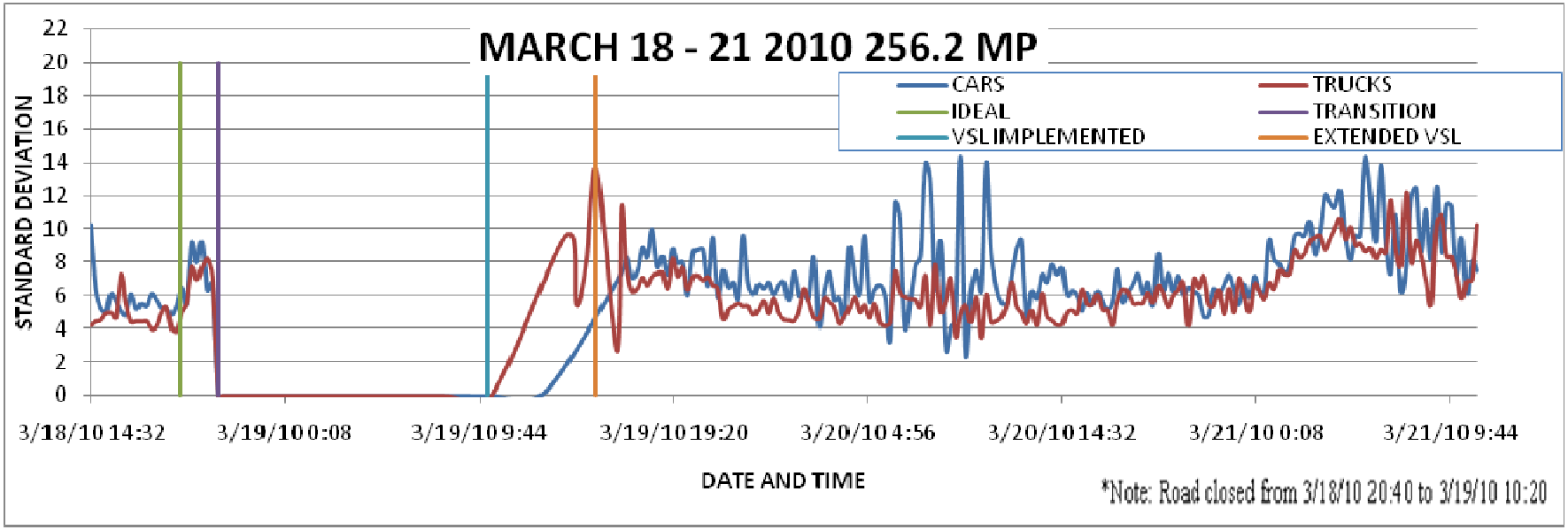
March 18-21, 2010 MILEPOST 289.5

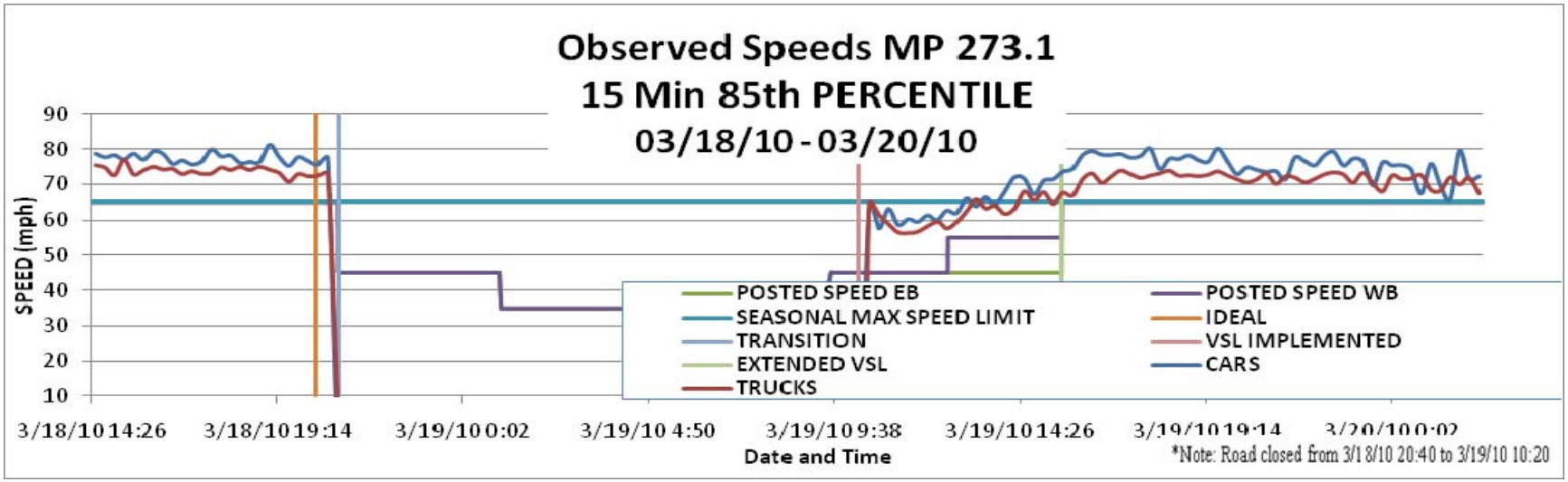
CARS	IDEAL	TRANSITION	VSL IMPLEMENTED	EXTENDED VSL
DURATION	3/18/2010 2:28:03 PM TO 3/18/2010 8:49:26 PM	3/18/2010 8:49:26 PM TO 3/19/2010 1:01:26 AM	3/19/2010 1:01:26 AM TO 3/19/2010 6:29:26 AM	3/19/2010 6:29:26 AM TO 3/19/2010 3:20:21 PM
# OBSERVATIONS	1426	N/A	N/A	1012
AVG SPEED	71.95	N/A	N/A	56.75
85th % SPEED	72.94	N/A	N/A	65.77
STD DEVIATION	0.95	N/A	N/A	8.88

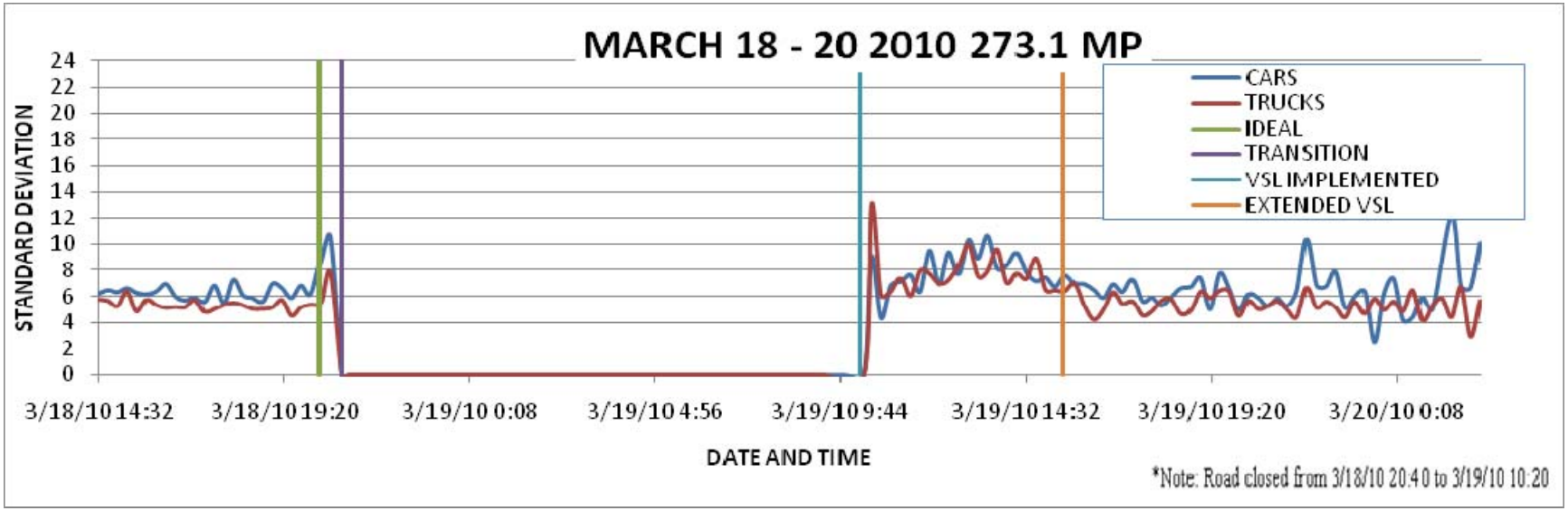
TRUCKS	IDEAL	TRANSITION	VSL IMPLEMENTED	EXTENDED VSL
DURATION	3/18/2010 2:28:03 PM TO 3/18/2010 8:49:26 PM	3/18/2010 8:49:26 PM TO 3/19/2010 1:01:26 AM	3/19/2010 1:01:26 AM TO 3/19/2010 6:29:26 AM	3/19/2010 6:29:26 AM TO 3/19/2010 3:20:21 PM
# OBSERVATIONS	1994	N/A	N/A	2431
AVG SPEED	67.10	N/A	N/A	52.86
85th % SPEED	67.72	N/A	N/A	61.40
STD DEVIATION	0.72	N/A	N/A	8.24

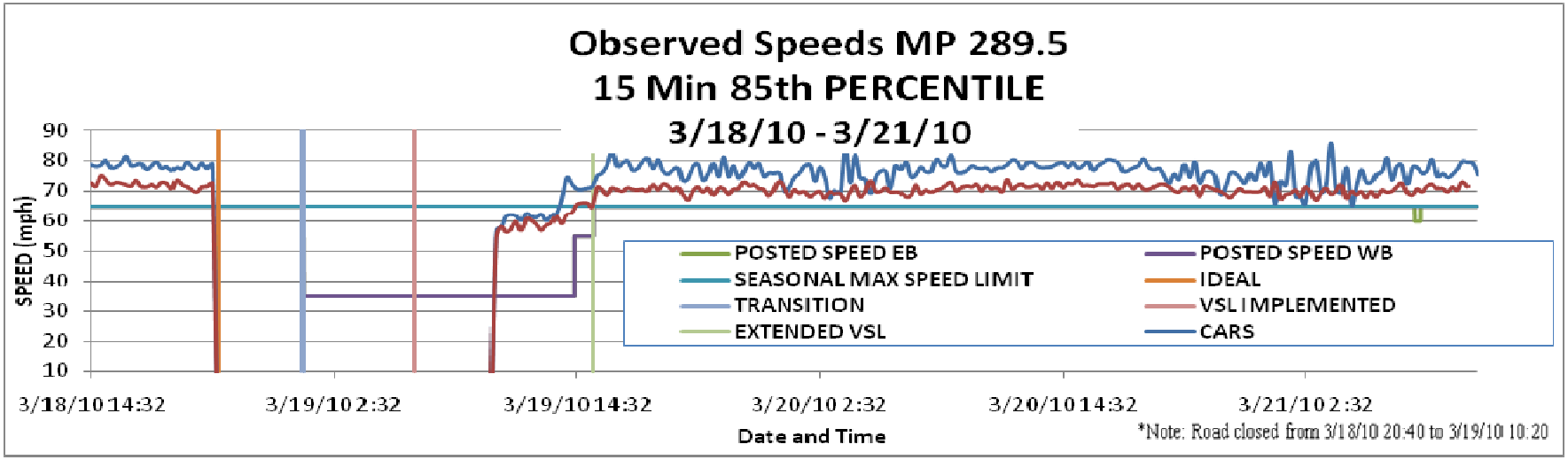
Calculations based on 15 minute Average Speeds

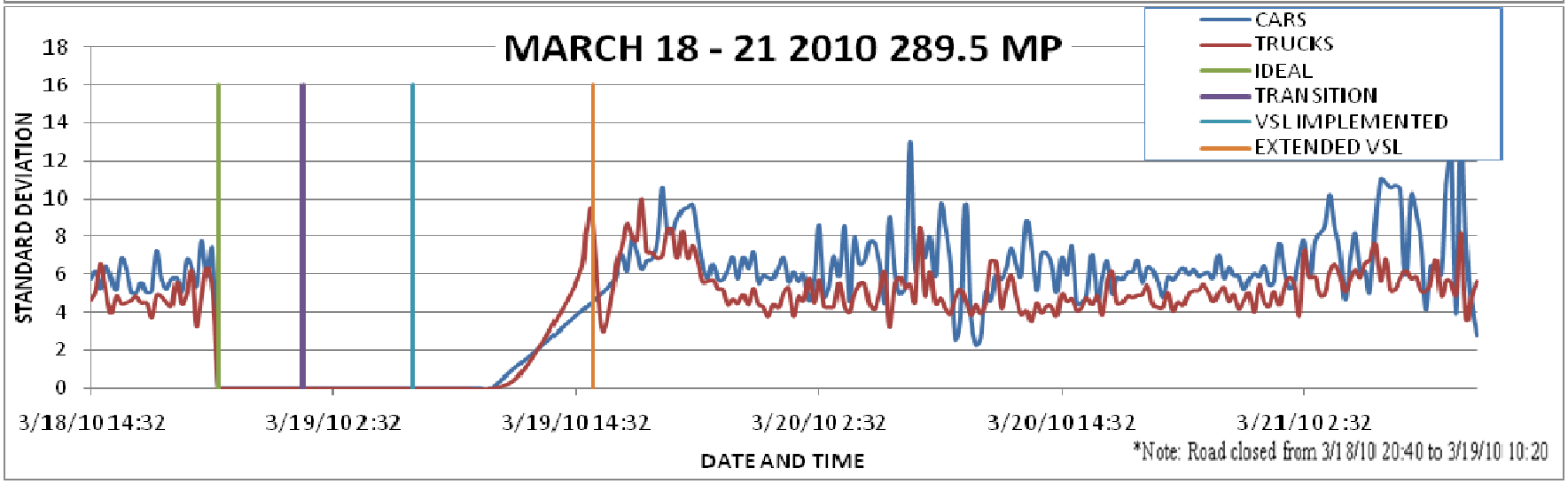

Observed Speeds MP 256.2
15 Min 85th PERCENTILE
03/18/10 - 03/21/10
SPEED (MPH)
110
100
90
80
70
60
50
40
30
20
10
IDEAL
TRANSITION
VSL IMPLEMENTED
EXTENDED VSL
POSTED SPEED EB
POSTED SPEED WB
SEASONAL MAX SPEED LIMIT
CARS
3/18/10 14:27
3/19/10 0:03
3/19/10 9:39
3/19/10 19:15
3/20/10 4:51
3/20/10 14:27
3/21/10 0:03
3/21/10 9:39
Date and Time
*Note: Road closed from 3/18/10 20:40 to 3/19/10 10:20

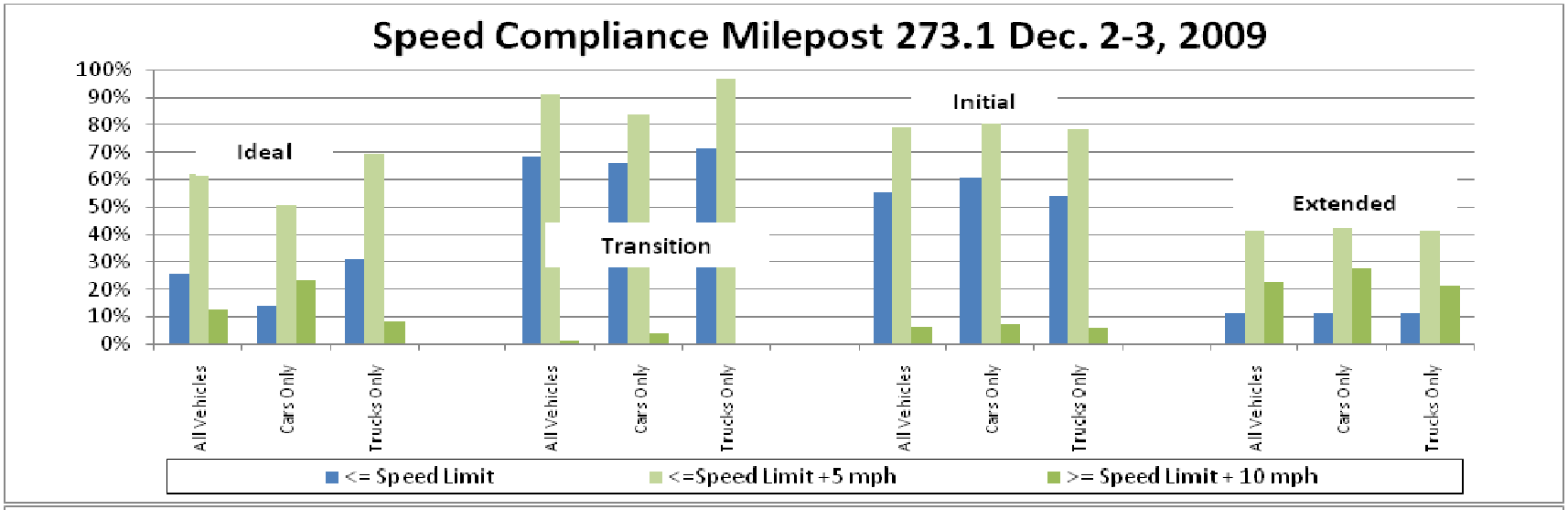

MARCH 18 - 21 2010 256.2 MP
STANDARD DEVIATION
22
20
18
16
14
12
10
8
6
4
2
0
CARS
TRUCKS
IDEAL
TRANSITION
VSL IMPLEMENTED
EXTENDED VSL
3/18/10 14:32
3/19/10 0:08
3/19/10 9:44
3/19/10 19:20
3/20/10 4:56
3/20/10 14:32
3/21/10 0:08
3/21/10 9:44
DATE AND TIME
*Note: Road closed from 3/18/10 20:40 to 3/19/10 10:20

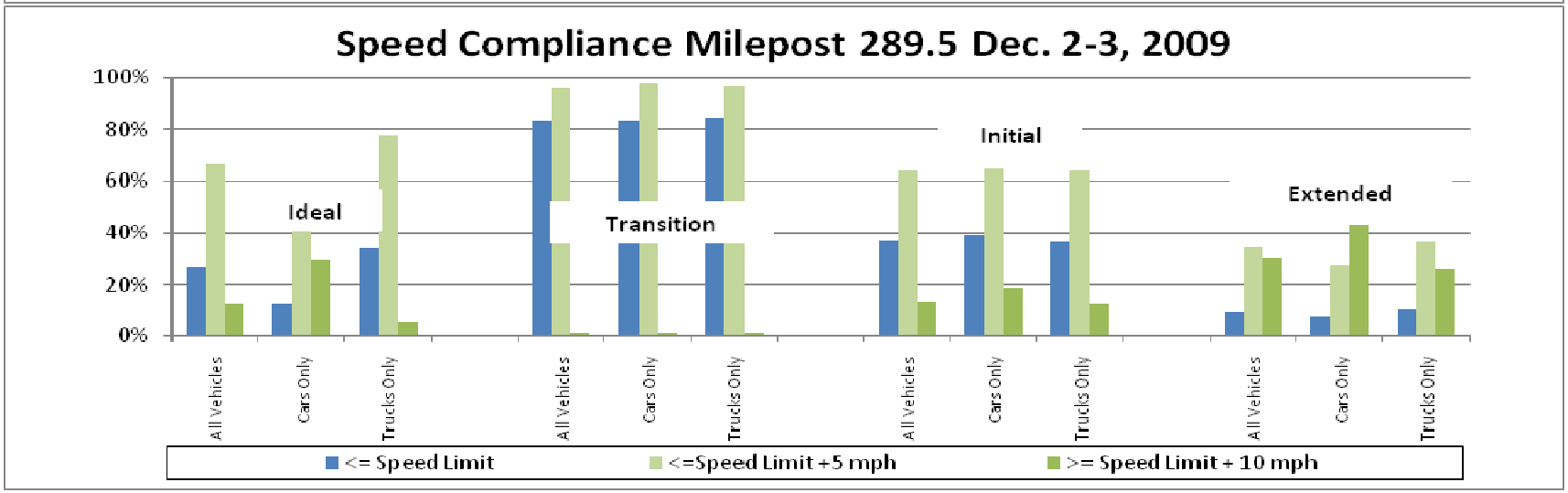

Observed Speeds MP 273.1
15 Min 85th PERCENTILE
03/18/10 - 03/20/10
SPEED (mph)
90
80
70
60
50
40
30
20
10
POSTED SPEED EB
POSTED SPEED WB
SEASONAL MAX SPEED LIMIT
IDEAL
TRANSITION
VSL IMPLEMENTED
EXTENDED VSL
CARS
TRUCKS
3/18/10 14:26
3/18/10 19:14
3/19/10 0:02
3/19/10 4:50
3/19/10 9:38
3/19/10 14:26
Date and Time
*Note: Road closed from 3/18/10 20:40 to 3/19/10 10:20


MARCH 18 - 20 2010 273.1 MP
STANDARD DEVIATION
24
22
20
18
16
14
12
10
8
6
4
2
0
CARS
TRUCKS
IDEAL
TRANSITION
VSL IMPLEMENTED
EXTENDED VSL
3/18/10 14:32
3/18/10 19:20
3/19/10 0:08
3/19/10 4:56
3/19/10 9:44
3/19/10 14:32
3/19/10 19:20
3/20/10 0:08
DATE AND TIME
*Note: Road closed from 3/18/10 20:40 to 3/19/10 10:20


Observed Speeds MP 289.5
15 Min 85th PERCENTILE
3/18/10 - 3/21/10
SPEED (mph)
90
80
70
60
50
40
30
20
10
3/18/10 14:32
3/19/10 2:32
3/19/10 14:32
3/20/10 2:32
3/20/10 14:32
3/21/10 2:32
Date and Time
POSTED SPEED EB
POSTED SPEED WB
SEASONAL MAX SPEED LIMIT
IDEAL
TRANSITION
VSL IMPLEMENTED
EXTENDED VSL
CARS
*Note: Road closed from 3/18/10 20:40 to 3/19/10 10:20


MARCH 18 - 21 2010 289.5 MP
STANDARD DEVIATION
18
16
14
12
10
8
6
4
2
0
3/18/10 14:32
3/19/10 2:32
3/19/10 14:32
3/20/10 2:32
3/20/10 14:32
3/21/10 2:32
DATE AND TIME
CARS
TRUCKS
IDEAL
TRANSITION
VSL IMPLEMENTED
EXTENDED VSL
*Note: Road closed from 3/18/10 20:40 to 3/19/10 10:20

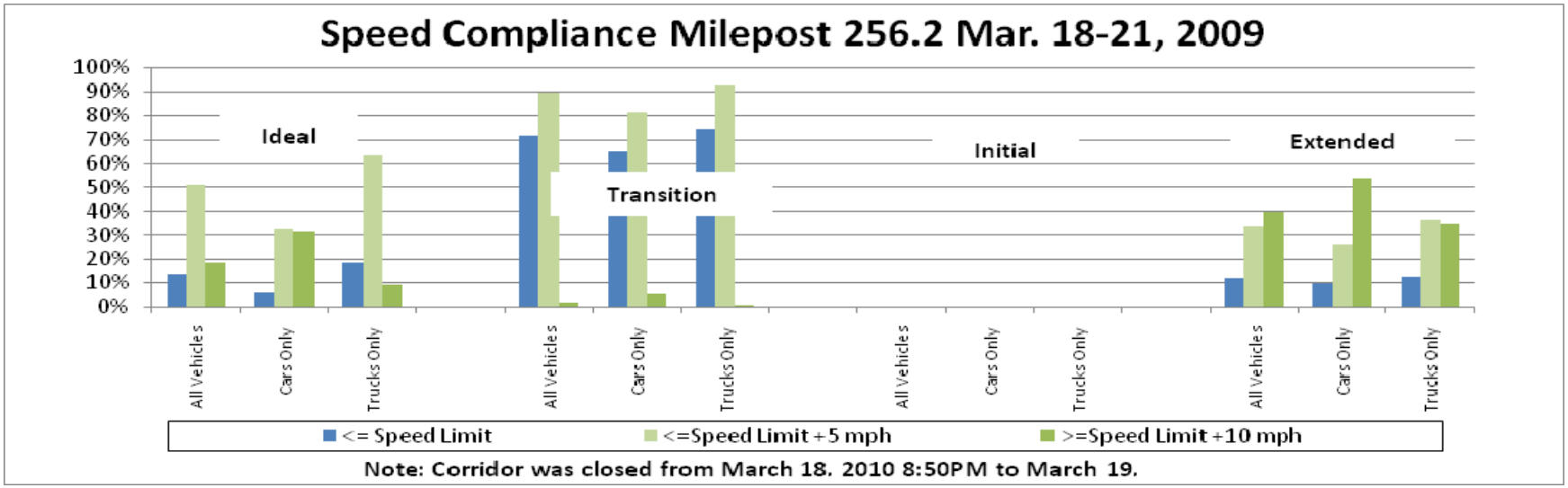

Speed Compliance Milepost 273.1 Dec. 2-3, 2009
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Ideal
Transition
Initial
Extended
All Vehicles
Cars Only
Trucks Only
<= Speed Limit
<=Speed Limit +5 mph
>= Speed Limit + 10 mph

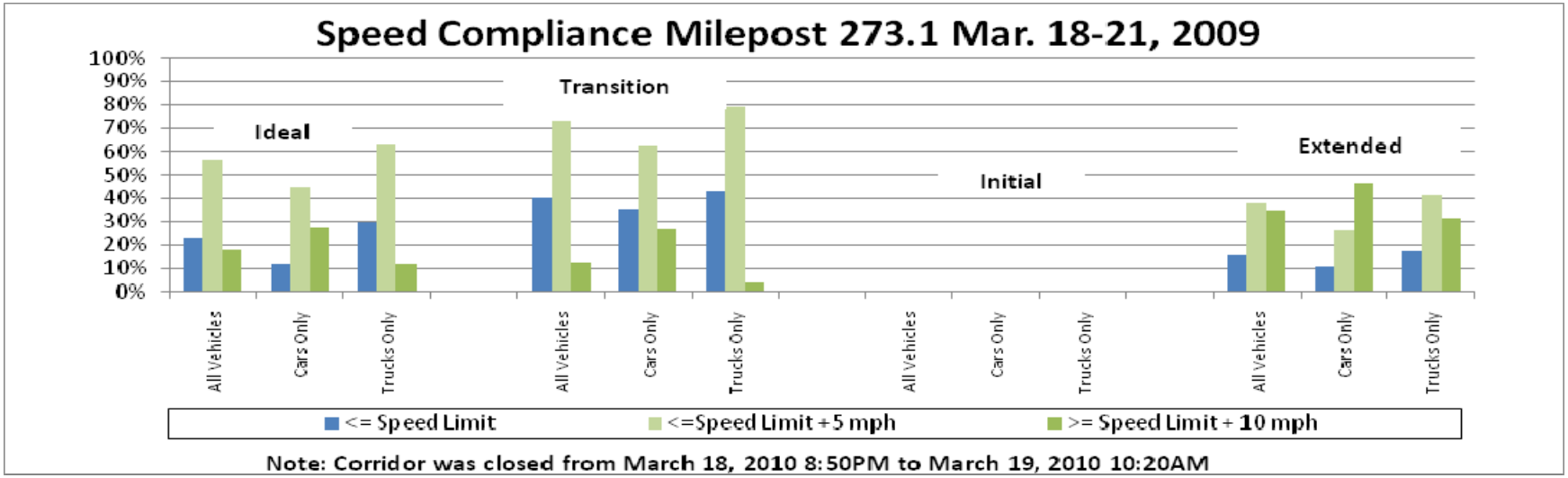

Speed Compliance Milepost 289.5 Dec. 2-3, 2009
100%
80%
60%
40%
20%
0%
Ideal
Transition
Initial
Extended
All Vehicles
Cars Only
Trucks Only
<= Speed Limit
<=Speed Limit +5 mph
>= Speed Limit + 10 mph

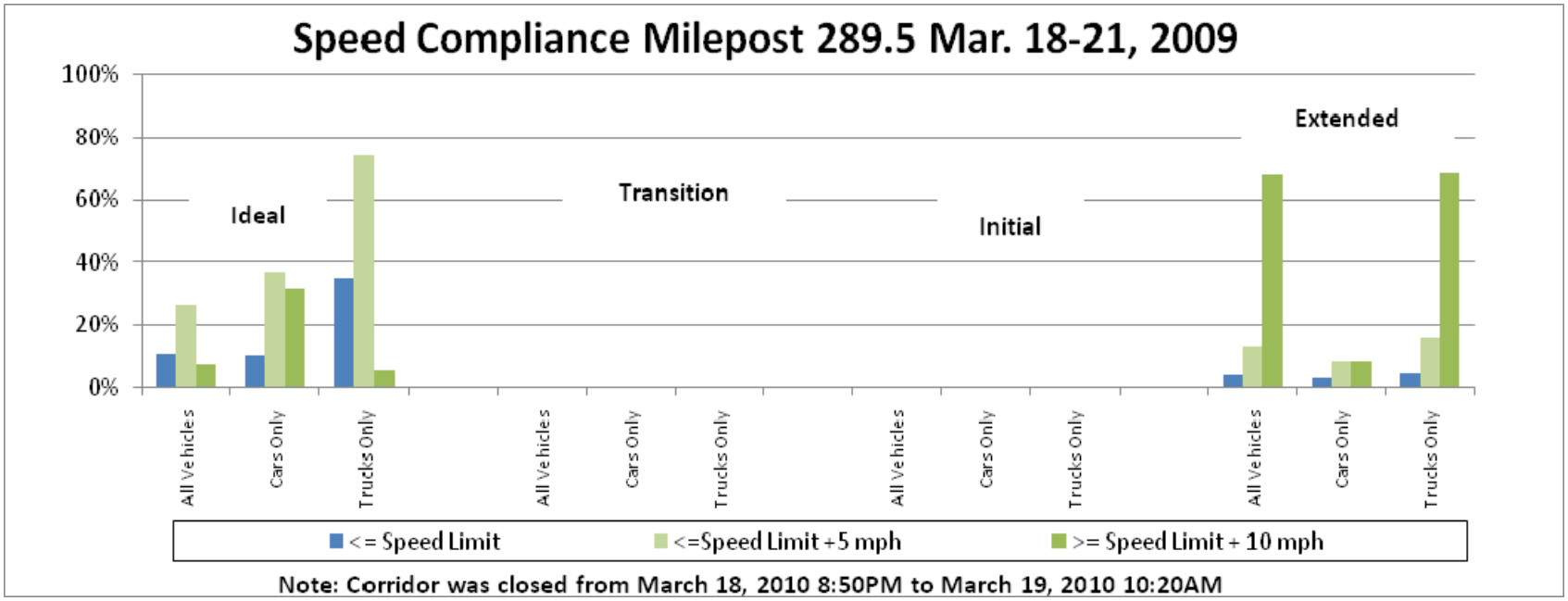
Speed Compliance Rates During March 18-21, 2009 Storm Event

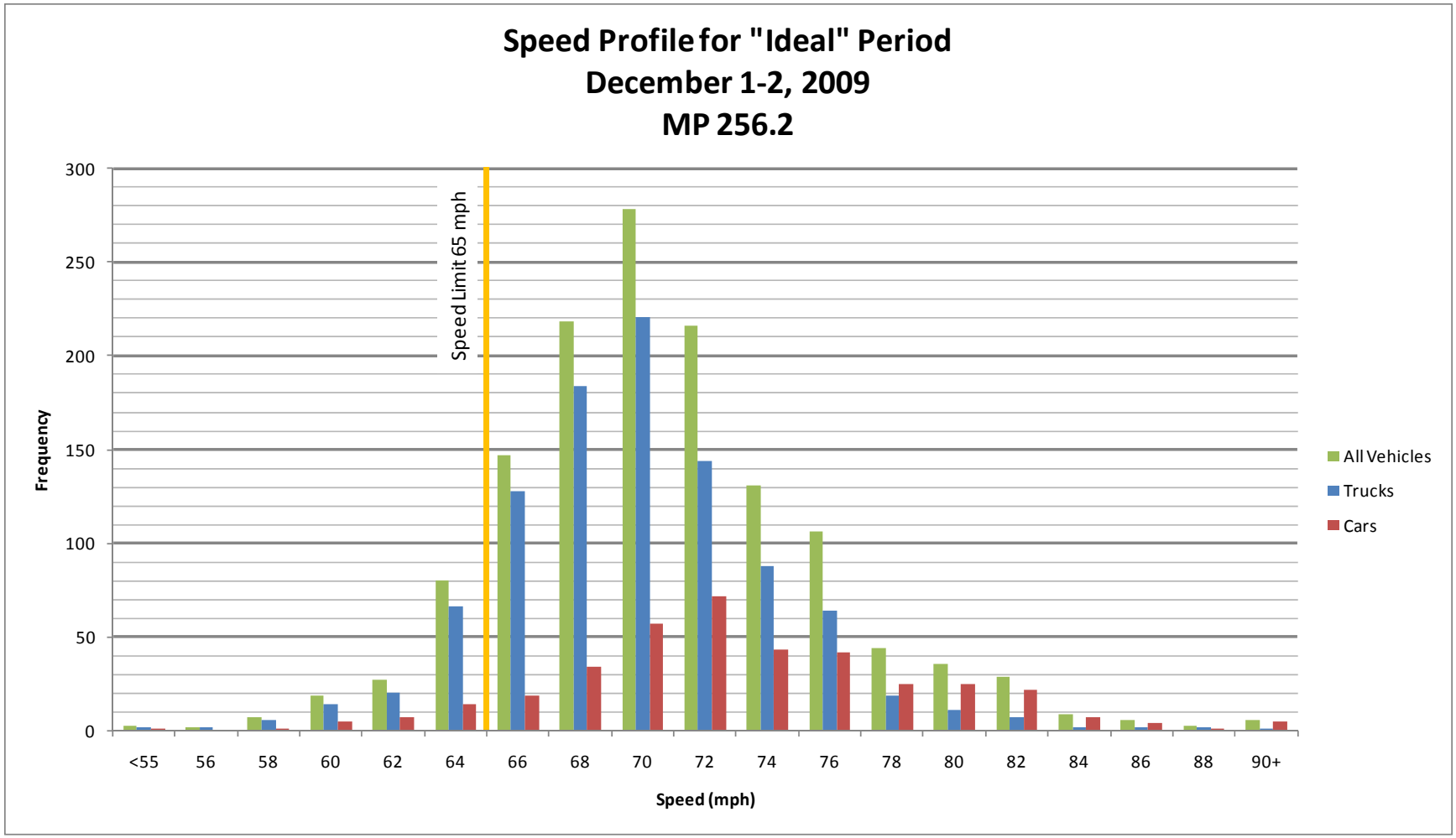
	MILEPOST 256.2			MILEPOST 273.1			MILEPOST 289.5		
	% AT OR BELOW POSTED SPEED	% AT OR BELOW POSTED SPEED +5MPH	% AT OR ABOVE POSTED SPEED +10MPH	% AT OR BELOW POSTED SPEED	% AT OR BELOW POSTED SPEED +5MPH	% AT OR ABOVE POSTED SPEED +10MPH	% AT OR BELOW POSTED SPEED	% AT OR BELOW POSTED SPEED +5MPH	% AT OR ABOVE POSTED SPEED +10MPH
IDEAL PERIOD									
All Vehicles	13.7%	50.8%	18.4%	22.7%	56.4%	18.0%	11.0%	26.3%	7.3%
Cars Only	6.2%	32.8%	31.6%	11.8%	45.0%	27.5%	10.4%	37.2%	31.6%
Trucks Only	18.9%	63.2%	9.3%	29.4%	63.5%	11.6%	34.8%	74.6%	5.5%
TRANSITION PERIOD									
All Vehicles	71.8%	89.6%	2.0%	40%	73%	12%	N/A	N/A	N/A
Cars Only	65.1%	81.3%	5.7%	35.4%	62.5%	27.1%	N/A	N/A	N/A
Trucks Only	74.8%	93.1%	0.4%	43.2%	79.0%	3.7%	N/A	N/A	N/A
INITIAL REDUCED SPEED									
All Vehicles	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Cars Only	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Trucks Only	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
EXTENDED REDUCED SPEED									
All Vehicles	12.0%	33.6%	39.8%	15.9%	38.1%	34.6%	3.9%	13.2%	68.3%
Cars Only	9.9%	25.7%	53.7%	10.5%	26.4%	46.4%	3%	8%	8%
Trucks Only	12.7%	36.3%	35.0%	17.2%	41.3%	31.2%	4.3%	15.8%	68.8%

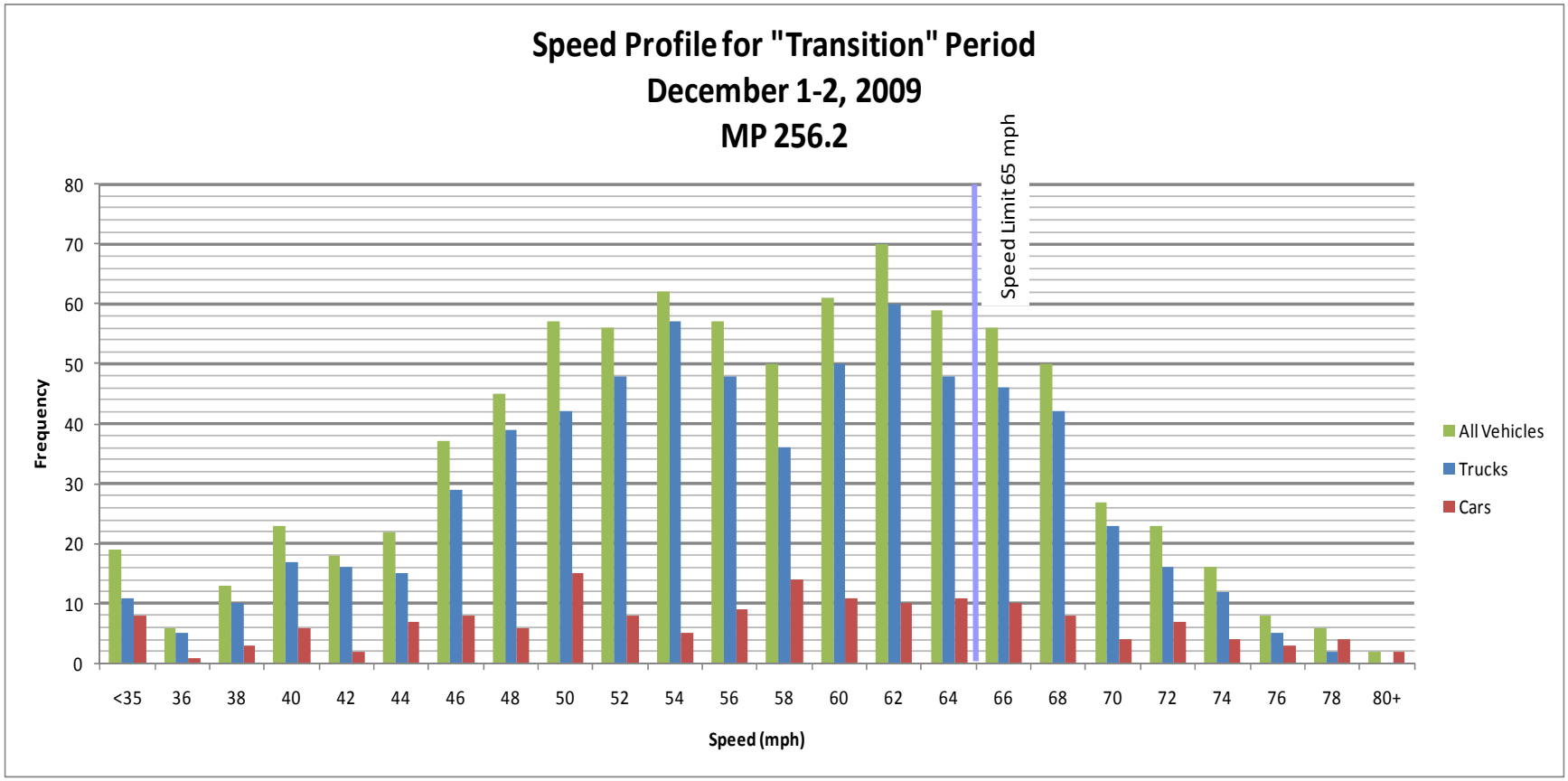
Note: Corridor was closed from March 18, 2010 8:50PM to March 19, 2010 10:20AM

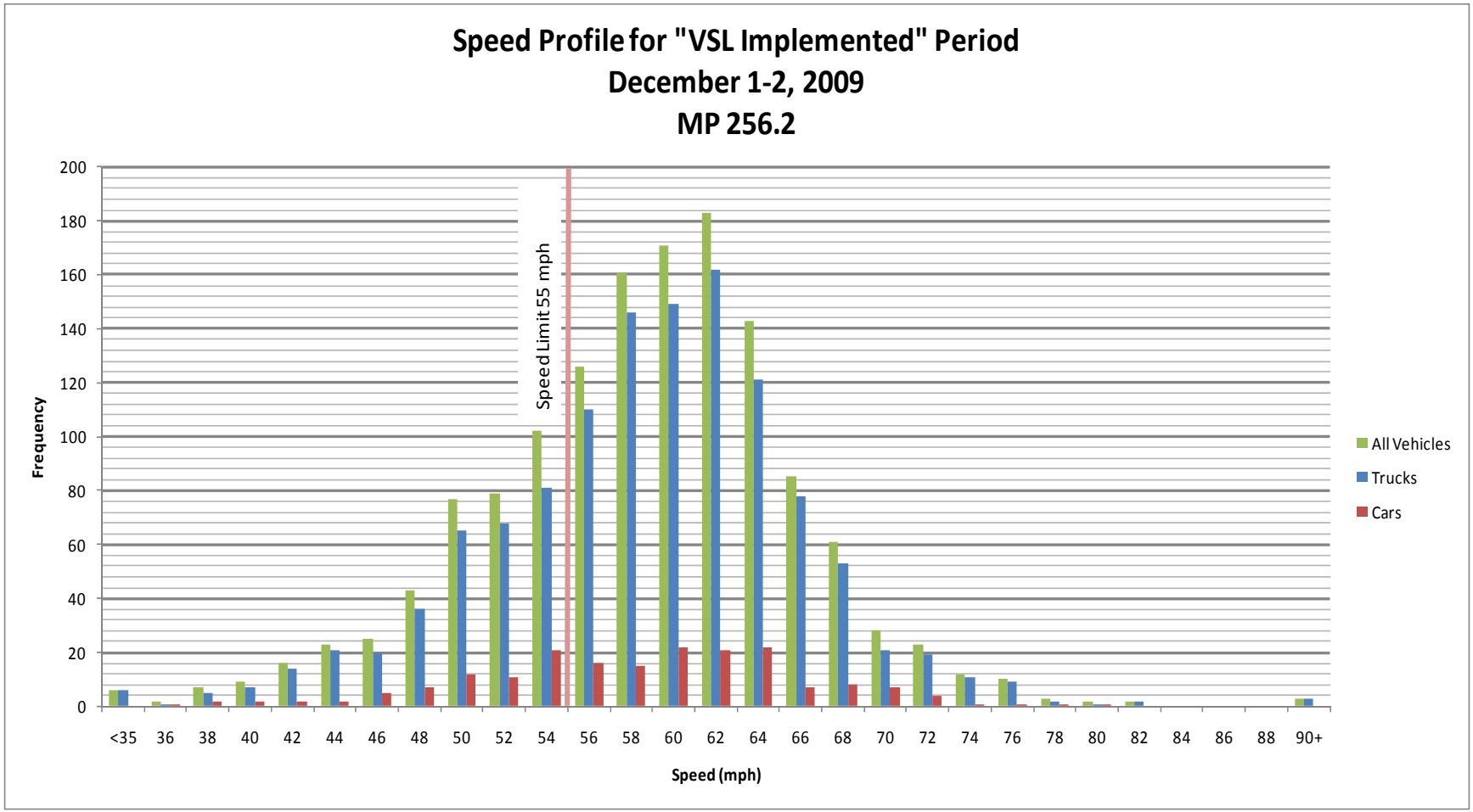

Speed Compliance Milepost 256.2 Mar. 18-21, 2009
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Ideal
Transition
Initial
Extended
All Vehicles
Cars Only
Trucks Only
<= Speed Limit
<=Speed Limit +5 mph
>=Speed Limit +10 mph
Note: Corridor was closed from March 18. 2010 8:50PM to March 19.

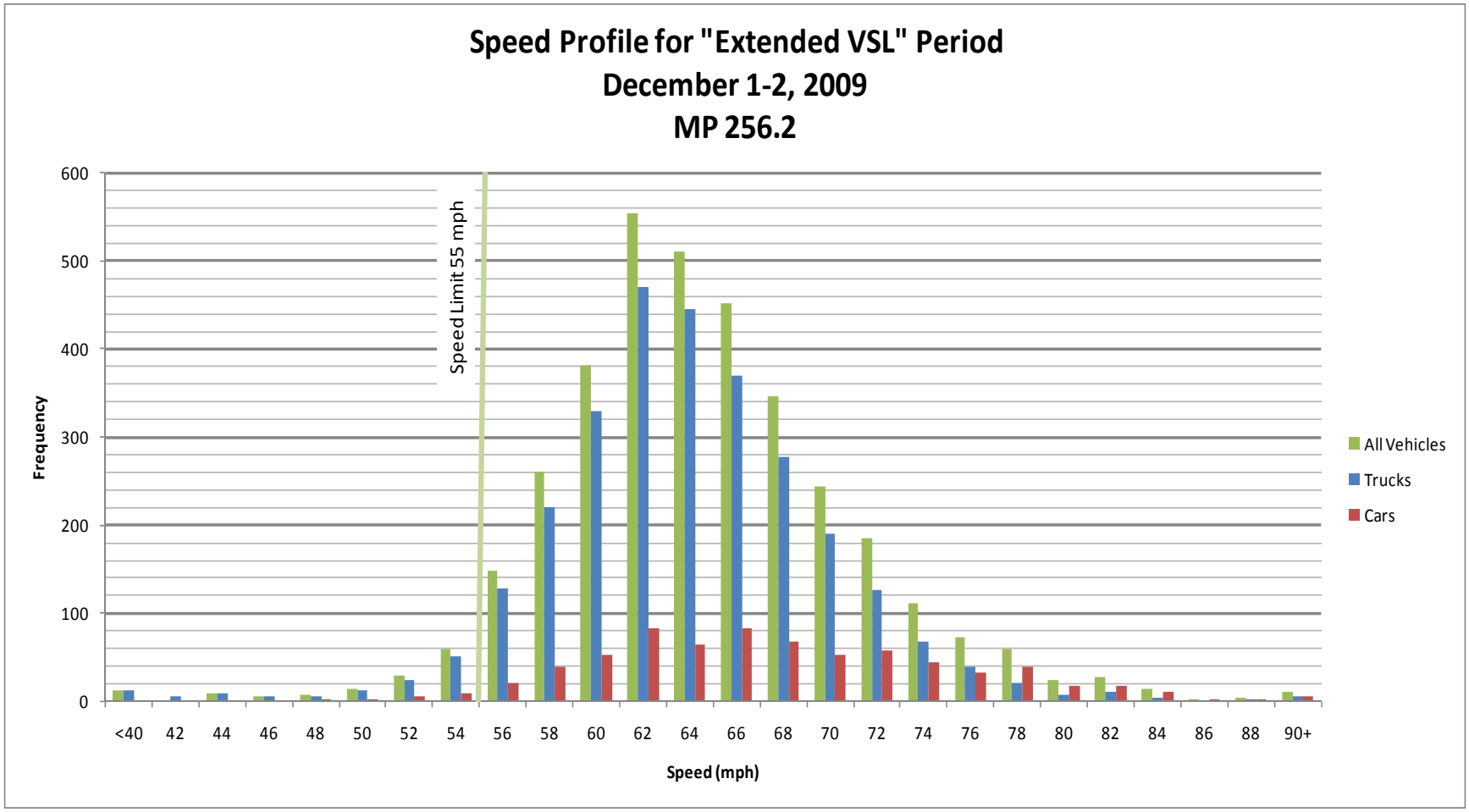

Speed Compliance Milepost 273.1 Mar. 18-21, 2009
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Ideal
Transition
Initial
Extended
All Vehicles
Cars Only
Trucks Only
<= Speed Limit
<=Speed Limit +5 mph
>= Speed Limit + 10 mph
Note: Corridor was closed from March 18, 2010 8:50PM to March 19, 2010 10:20AM

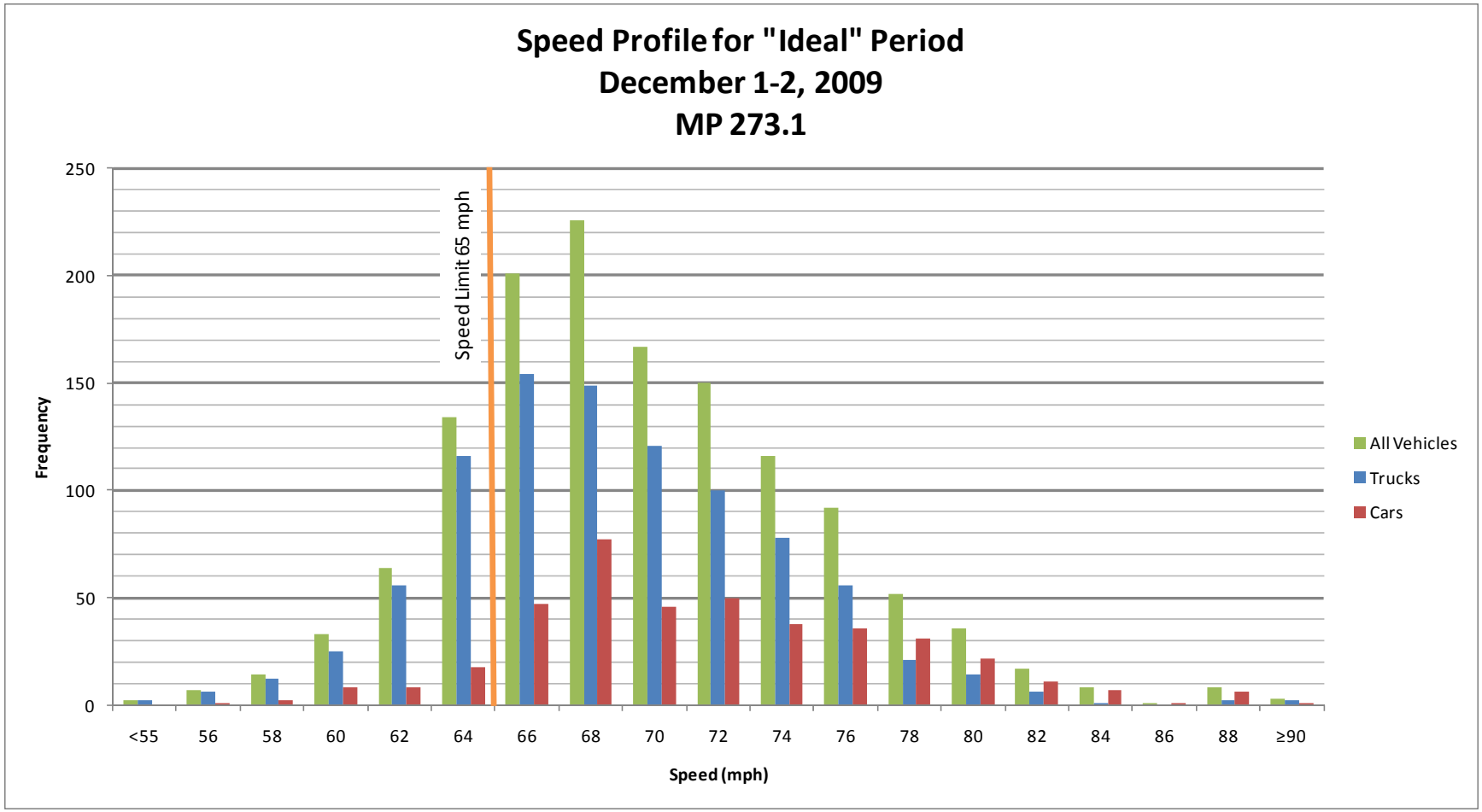

Speed Compliance Milepost 289.5 Mar. 18-21, 2009
100%
80%
60%
40%
20%
0%
Ideal
Transition
Initial
Extended
All Vehicles
Cars Only
Trucks Only
All Vehicles
Cars Only
Trucks Only
All Vehicles
Cars Only
Trucks Only
All Vehicles
Cars Only
Trucks Only
<= Speed Limit
<=Speed Limit + 5 mph
>= Speed Limit + 10 mph
Note: Corridor was closed from March 18, 2010 8:50PM to March 19, 2010 10:20AM

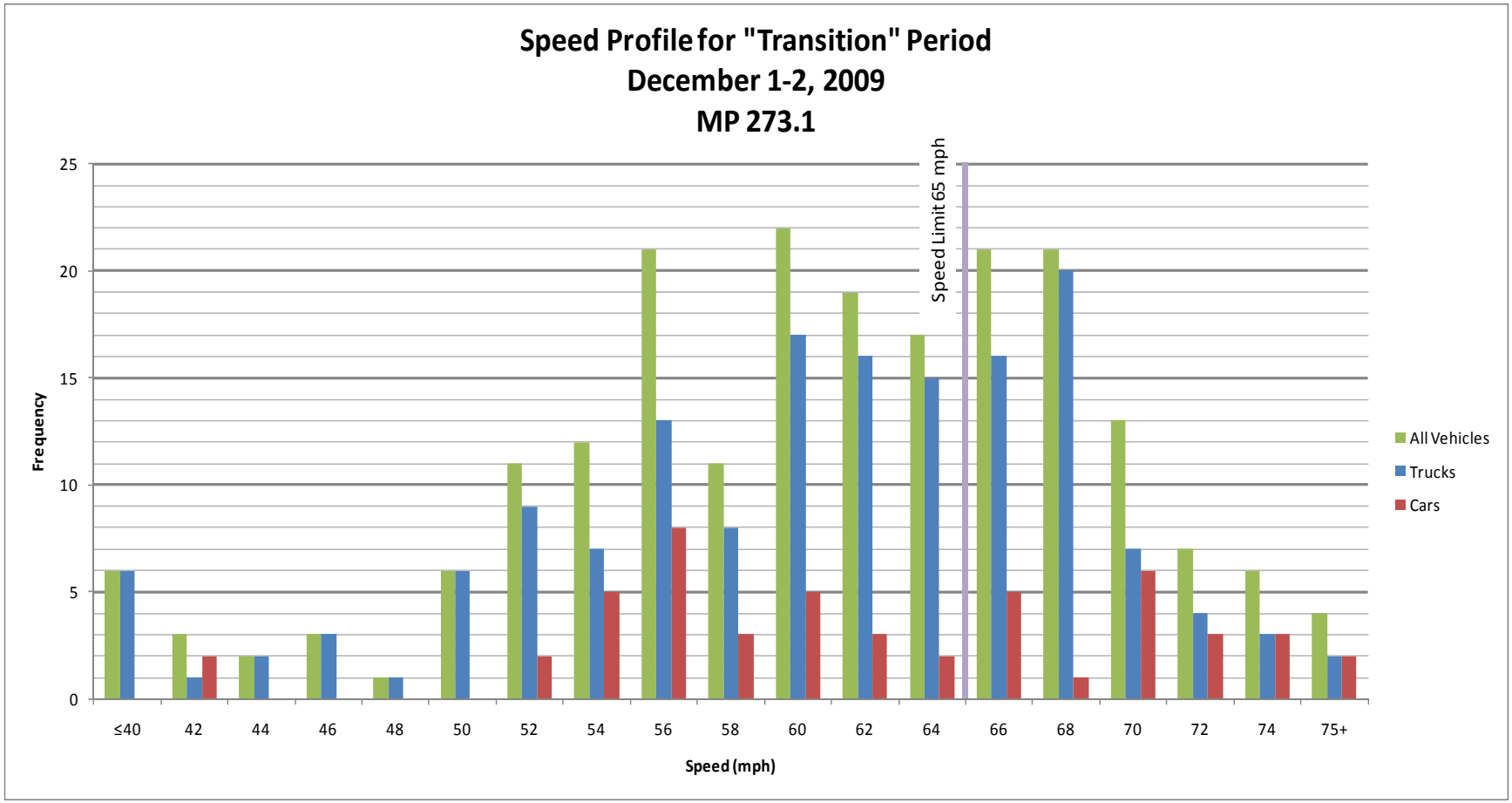

Speed Profile for "Ideal" Period
December 1-2, 2009
MP 256.2
Frequency
300
250
200
150
100
50
0
Speed Limit 65 mph
<55
56
58
60
62
64
66
68
70
72
74
76
78
80
82
84
86
88
90+
Speed (mph)
All Vehicles
Trucks
Cars

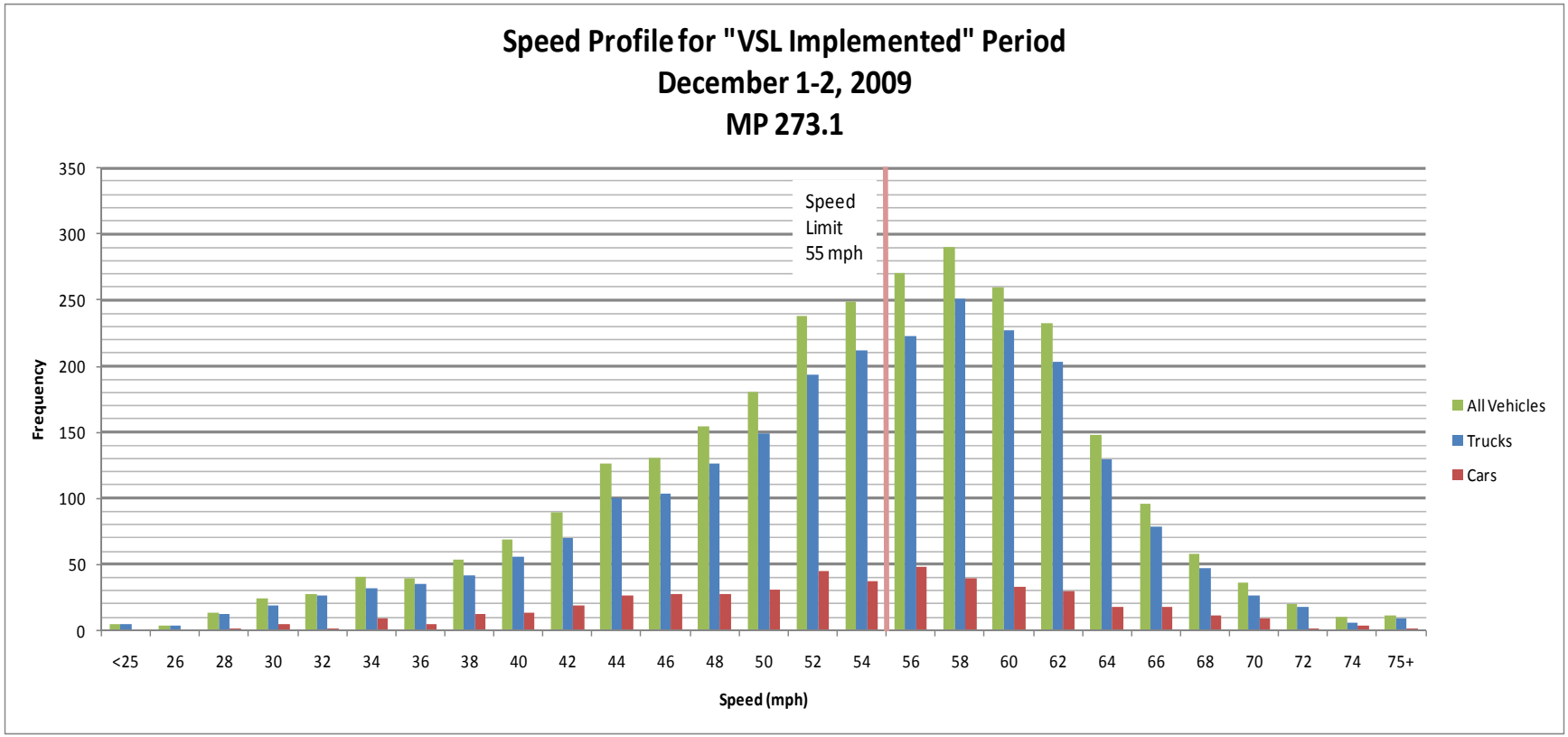

Speed Profile for "Transition" Period
December 1-2, 2009
MP 256.2
Speed Limit 65 mph
Frequency
0
10
20
30
40
50
60
70
80
<35
36
38
40
42
44
46
48
50
52
54
56
58
60
62
64
66
68
70
72
74
76
78
80+
Speed (mph)
All Vehicles
Trucks
Cars

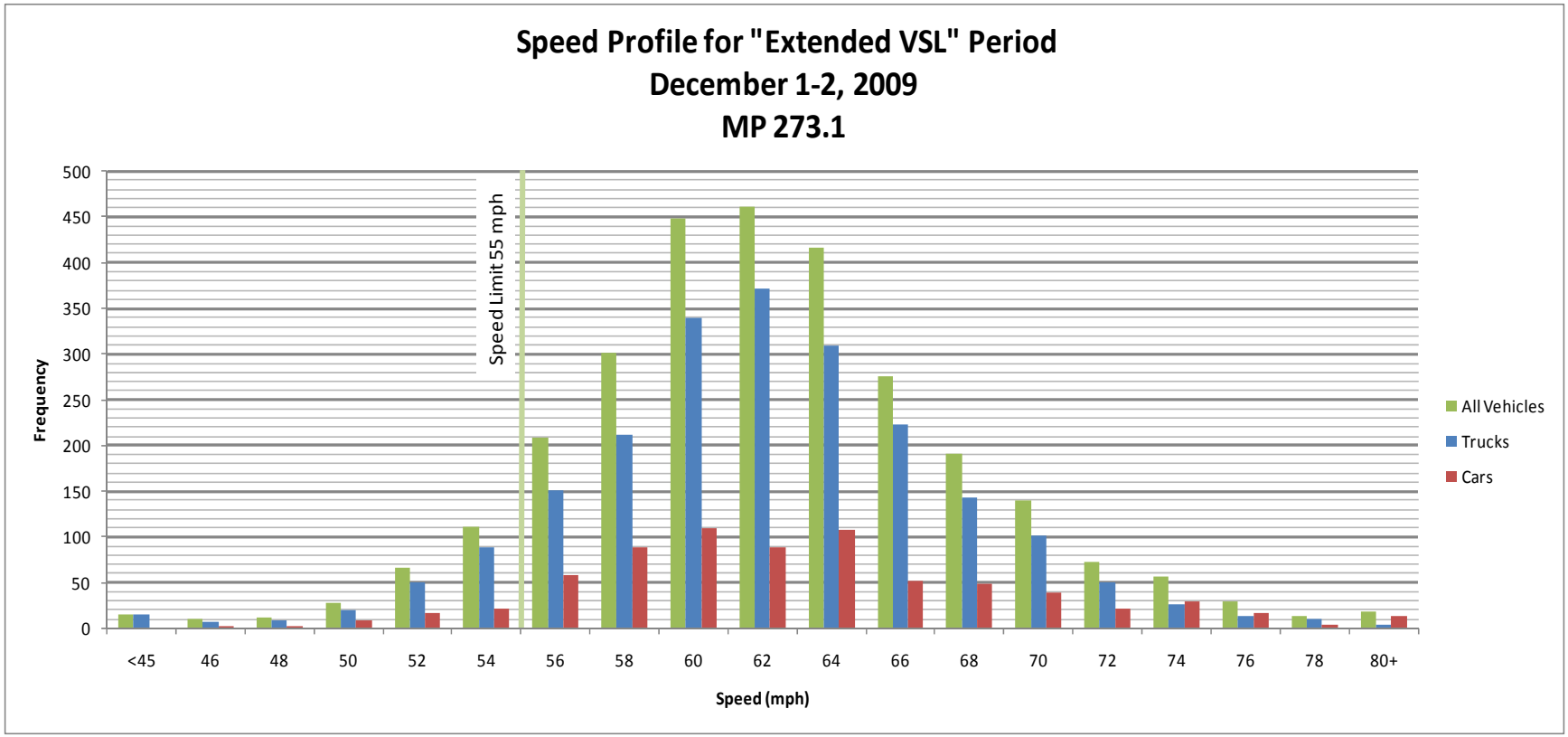

Speed Profile for "VSL Implemented" Period
December 1-2, 2009
MP 256.2
Frequency
200
180
160
140
120
100
80
60
40
20
0
Speed Limit 55 mph
<35
36
38
40
42
44
46
48
50
52
54
56
58
60
62
64
66
68
70
72
74
76
78
80
82
84
86
88
90+
Speed (mph)
All Vehicles
Trucks
Cars

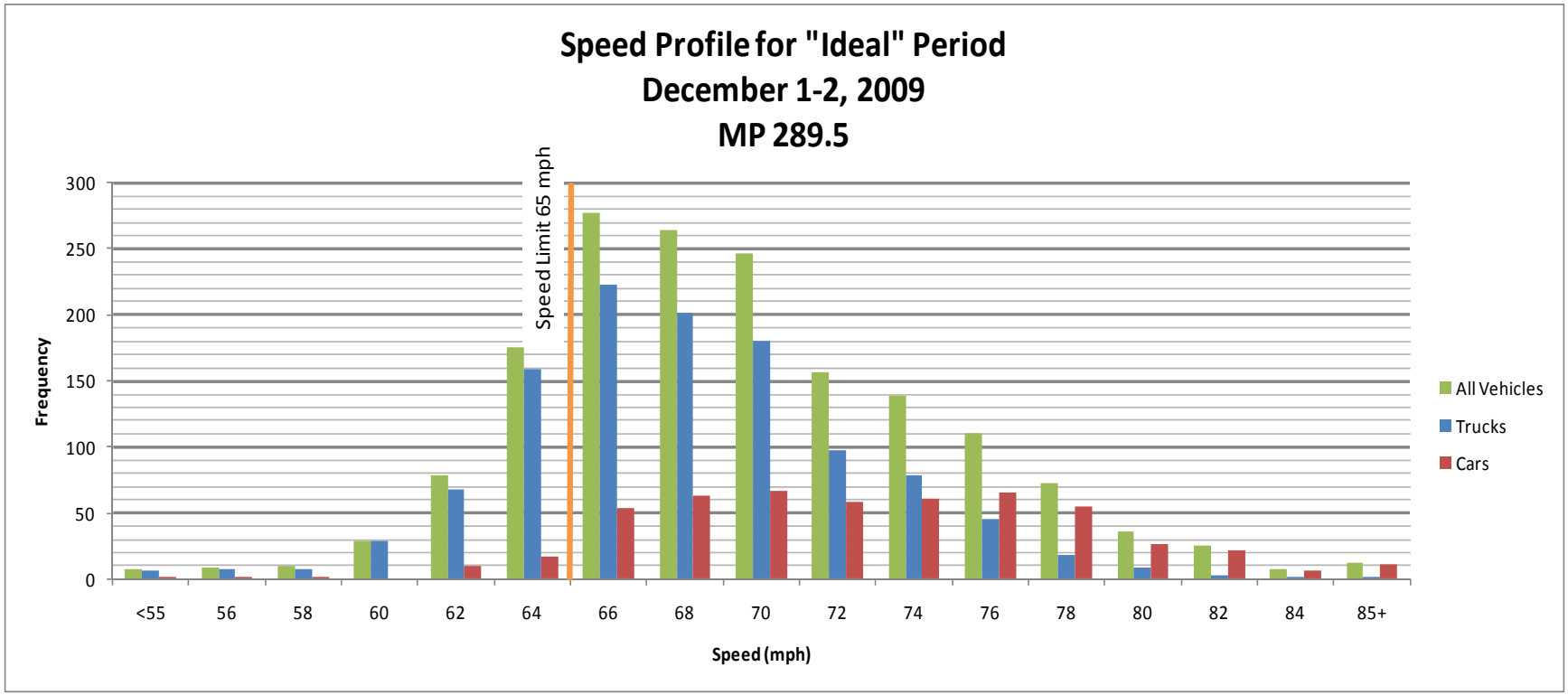

Speed Profile for "Extended VSL" Period
December 1-2, 2009
MP 256.2
Frequency
600
500
400
300
200
100
0
Speed Limit 55 mph
<40
42
44
46
48
50
52
54
56
58
60
62
64
66
68
70
72
74
76
78
80
82
84
86
88
90+
Speed (mph)
All Vehicles
Trucks
Cars

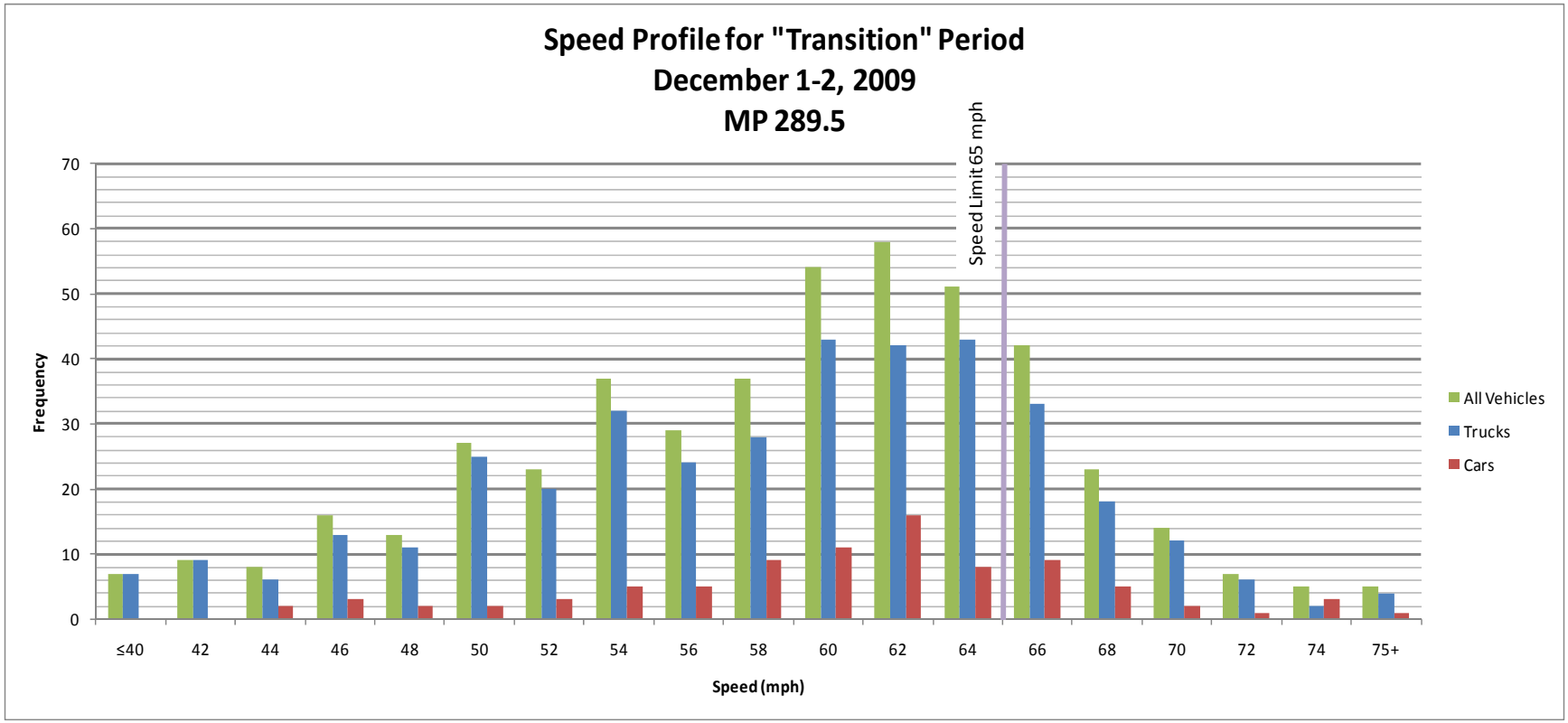

Speed Profile for "Ideal" Period
December 1-2, 2009
MP 273.1
Frequency
250
200
150
100
50
0
Speed Limit 65 mph
<55
56
58
60
62
64
66
68
70
72
74
76
78
80
82
84
86
88
≥90
Speed (mph)
All Vehicles
Trucks
Cars

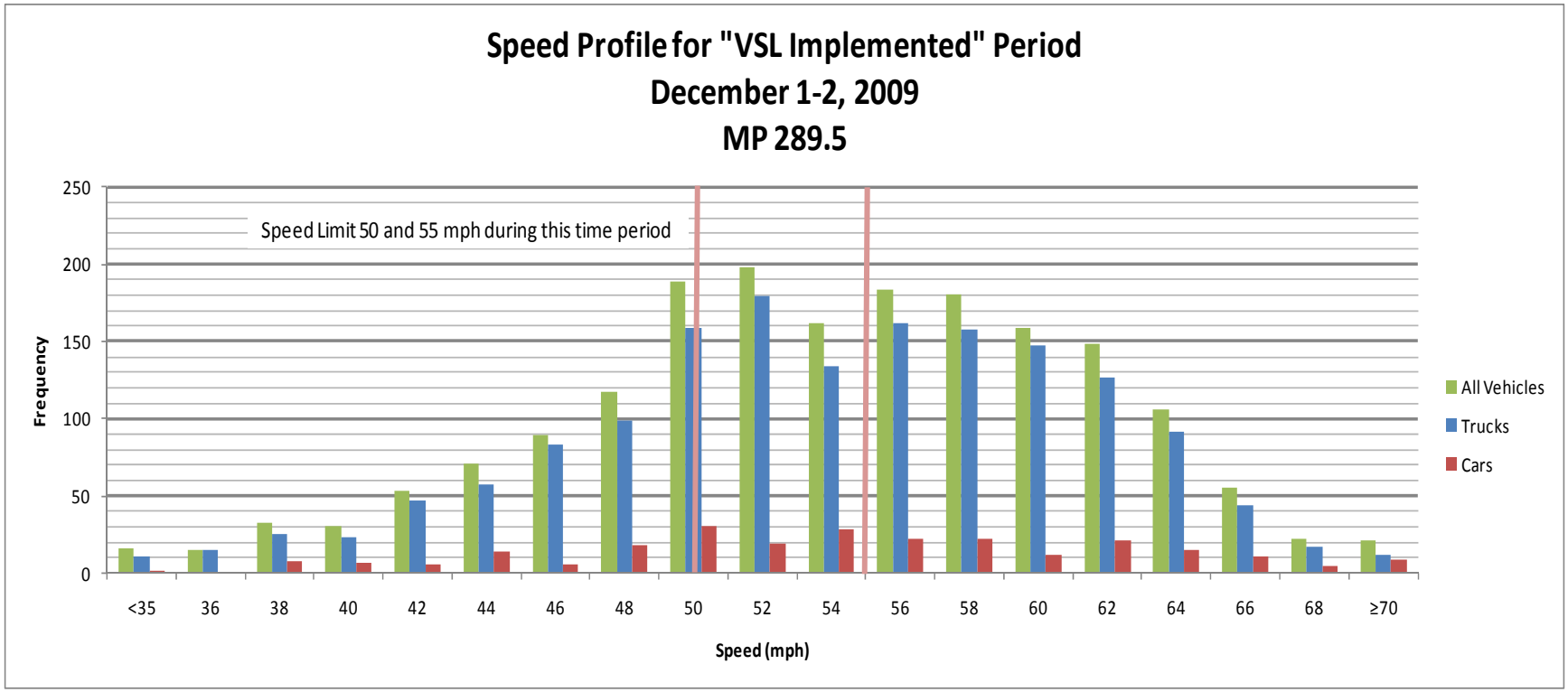

Speed Profile for "Transition" Period
December 1-2, 2009
MP 273.1
Speed Limit 65 mph
Frequency
25
20
15
10
5
0
≤40
42
44
46
48
50
52
54
56
58
60
62
64
66
68
70
72
74
75+
Speed (mph)
All Vehicles
Trucks
Cars

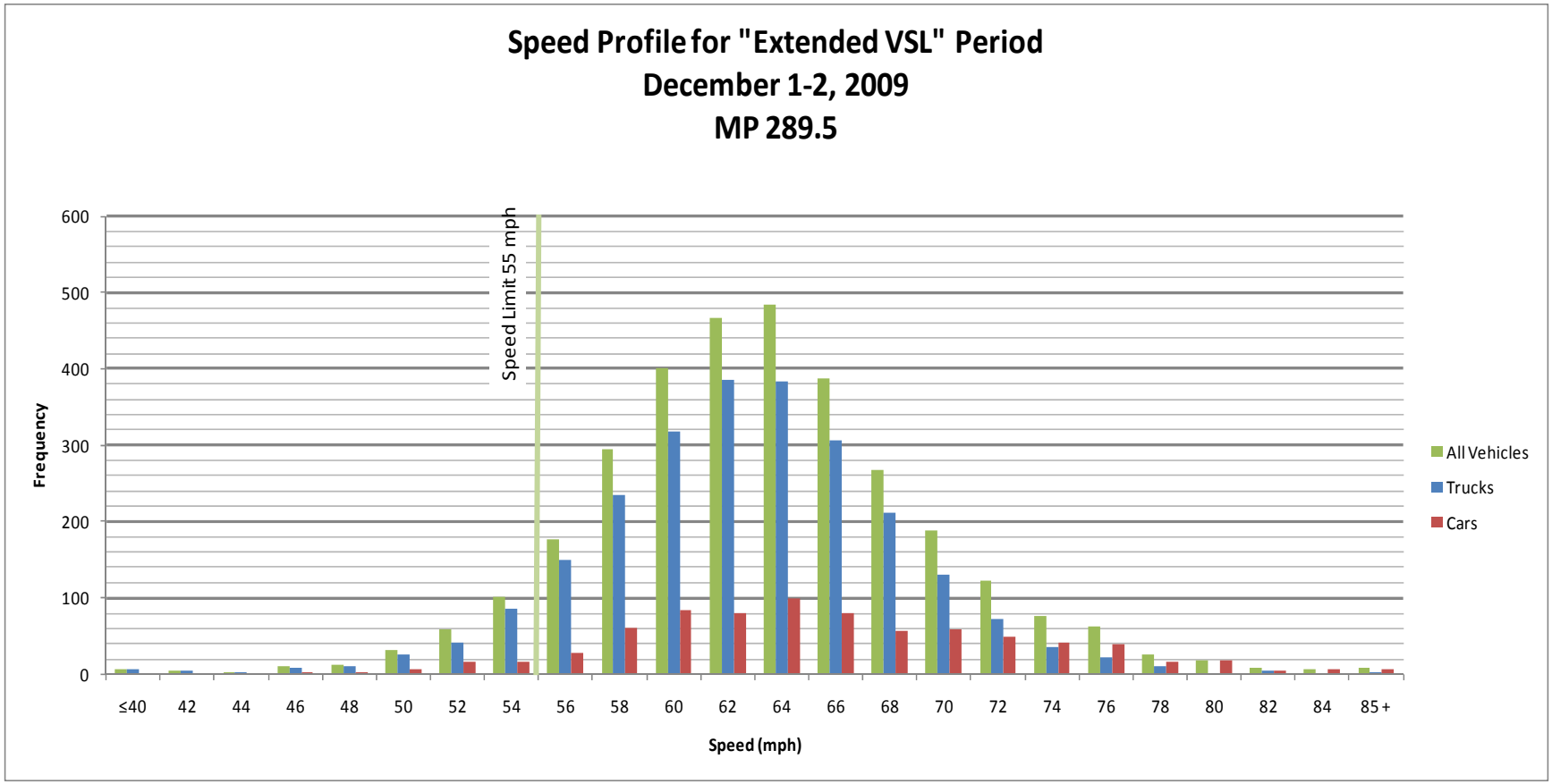

Speed Profile for "VSL Implemented" Period
December 1-2, 2009
MP 273.1
Speed
Limit
55 mph
Frequency
350
300
250
200
150
100
50
0
<25
26
28
30
32
34
36
38
40
42
44
46
48
50
52
54
56
58
60
62
64
66
68
70
72
74
75+
Speed (mph)
All Vehicles
Trucks
Cars

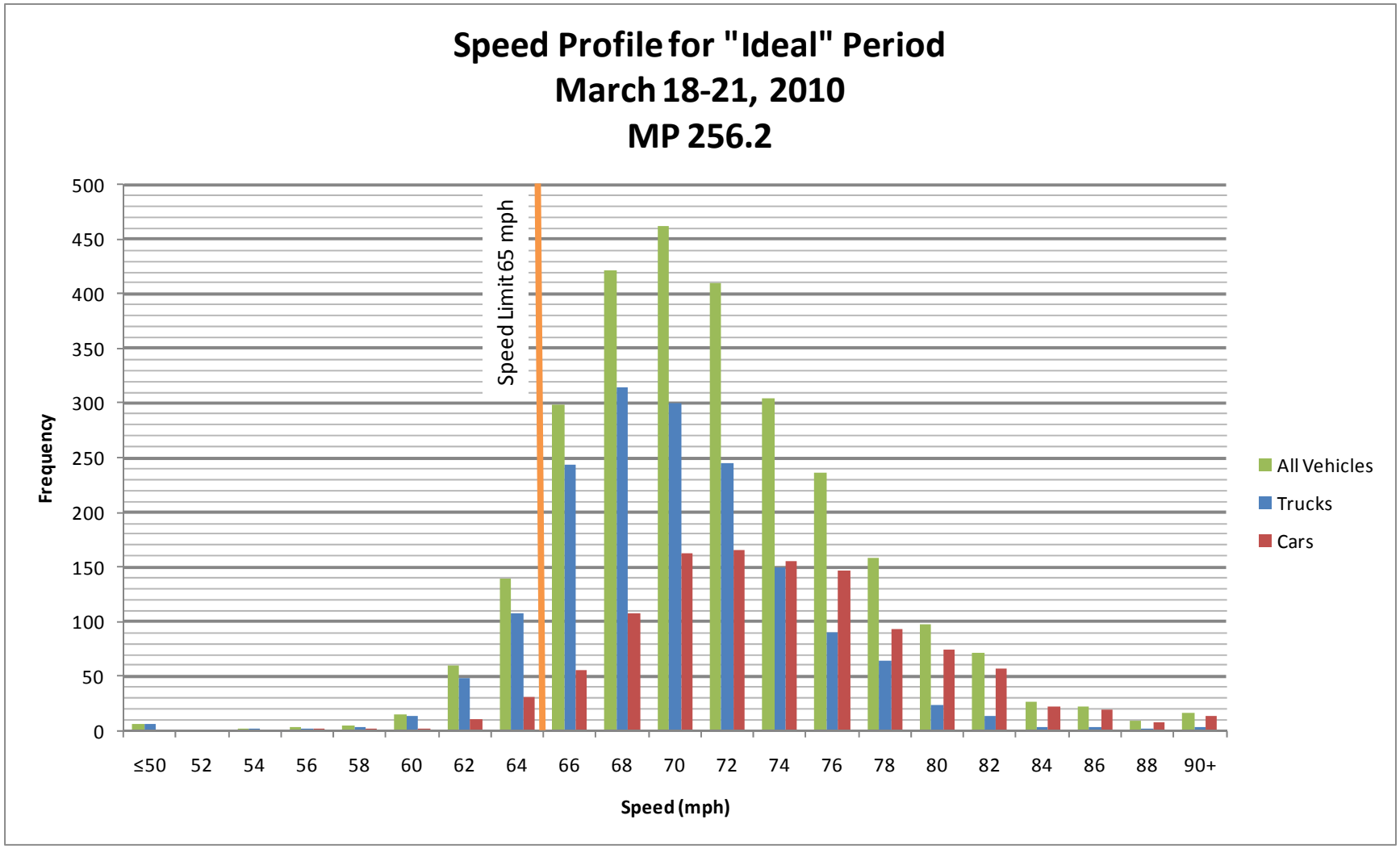

Speed Profile for "Extended VSL" Period
December 1-2, 2009
MP 273.1
Frequency
500
450
400
350
300
250
200
150
100
50
0
Speed Limit 55 mph
<45
46
48
50
52
54
56
58
60
62
64
66
68
70
72
74
76
78
80+
Speed (mph)
All Vehicles
Trucks
Cars

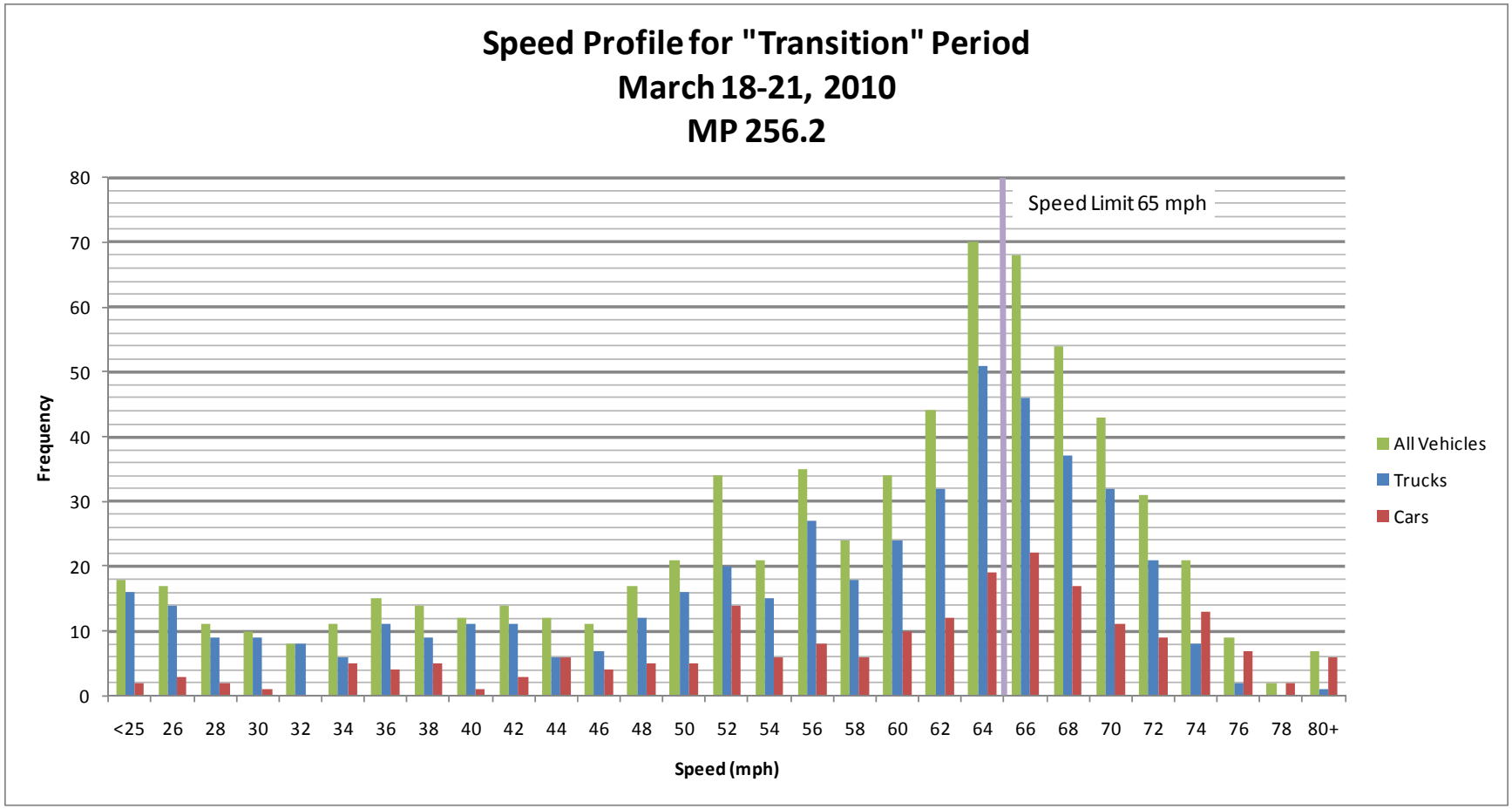

Speed Profile for "Ideal" Period
December 1-2, 2009
MP 289.5
Speed Limit 65 mph
Frequency
300
250
200
150
100
50
0
<55
56
58
60
62
64
66
68
70
72
74
76
78
80
82
84
85+
Speed (mph)
All Vehicles
Trucks
Cars


Speed Profile for "Transition" Period
December 1-2, 2009
MP 289.5
Speed Limit 65 mph
Frequency
70
60
50
40
30
20
10
0
≤40
42
44
46
48
50
52
54
56
58
60
62
64
66
68
70
72
74
75+
Speed (mph)
All Vehicles
Trucks
Cars

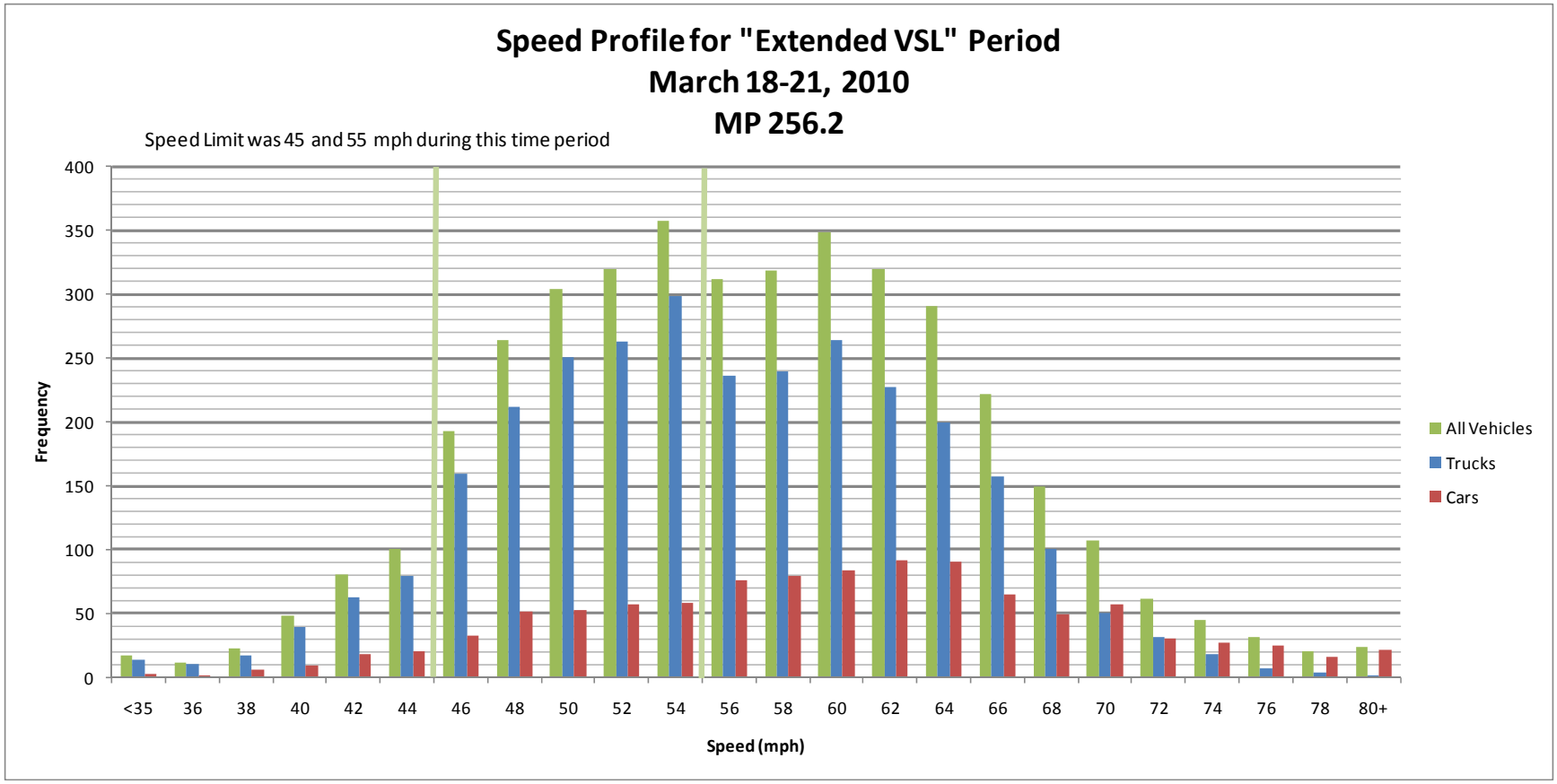

Speed Profile for "VSL Implemented" Period
December 1-2, 2009
MP 289.5
Speed Limit 50 and 55 mph during this time period
Frequency
250
200
150
100
50
0
<35
36
38
40
42
44
46
48
50
52
54
56
58
60
62
64
66
68
≥70
Speed (mph)
All Vehicles
Trucks
Cars

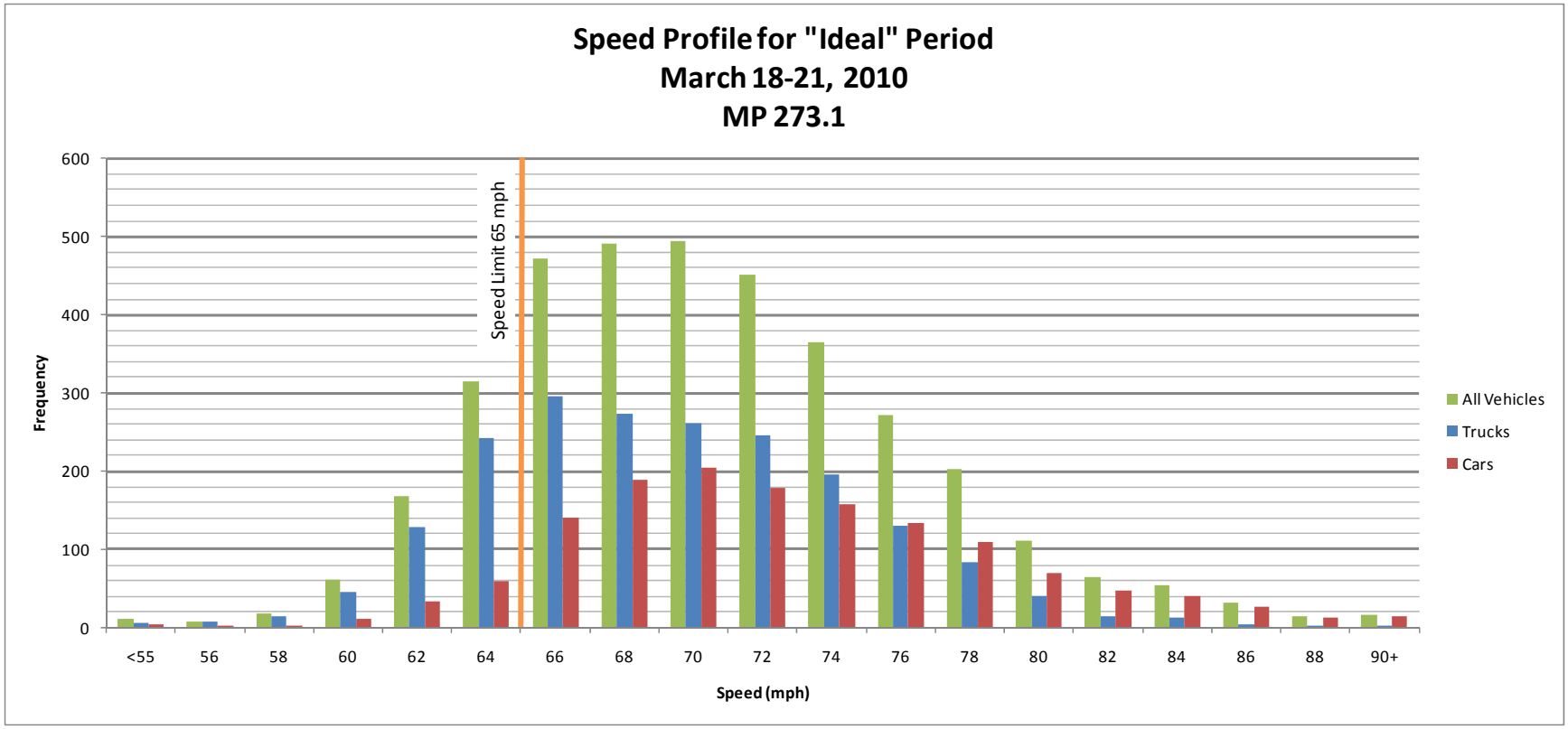

Speed Profile for "Extended VSL" Period
December 1-2, 2009
MP 289.5
Frequency
600
500
400
300
200
100
0
Speed Limit 55 mph
≤40
42
44
46
48
50
52
54
56
58
60
62
64
66
68
70
72
74
76
78
80
82
84
85+
Speed (mph)
All Vehicles
Trucks
Cars

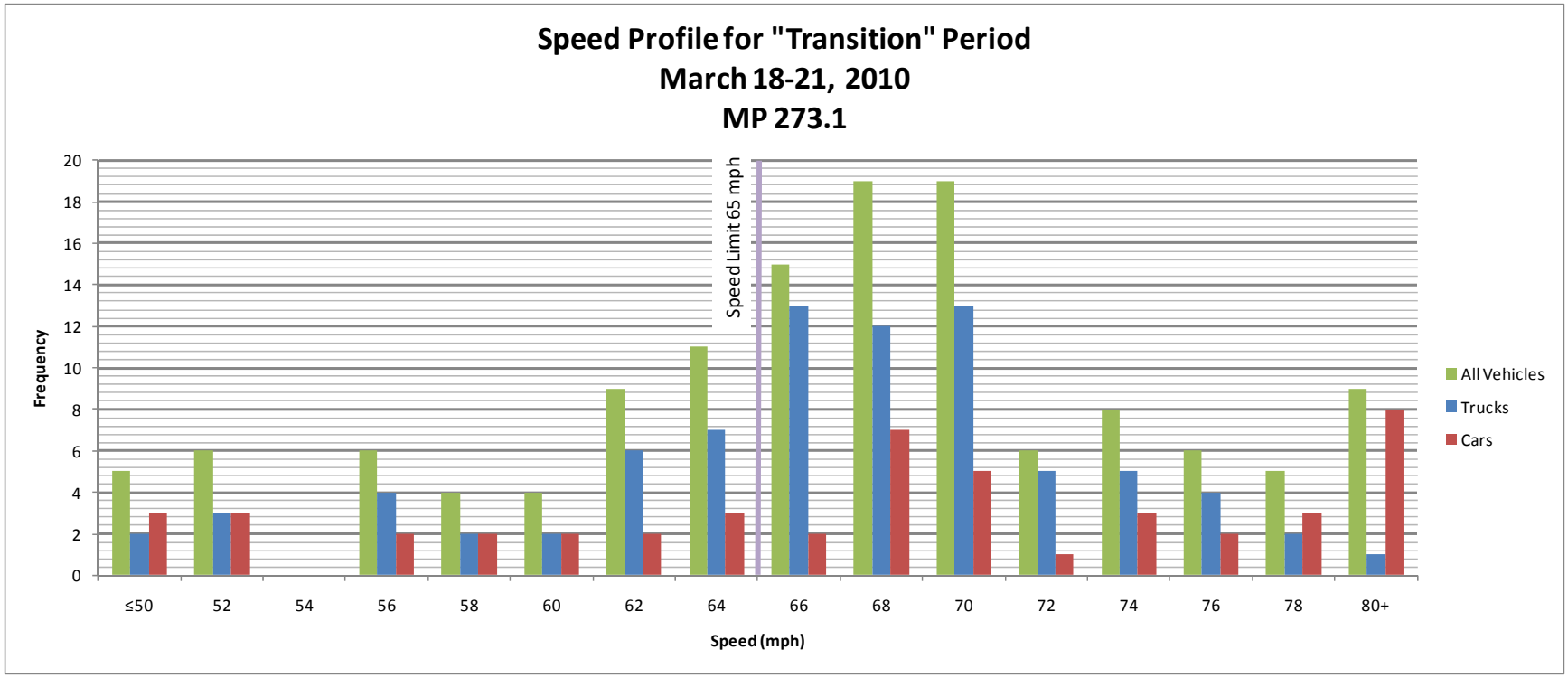

Speed Profile for "Ideal" Period
March 18-21, 2010
MP 256.2
Frequency
500
450
400
350
300
250
200
150
100
50
0
Speed Limit 65 mph
≤50
52
54
56
58
60
62
64
66
68
70
72
74
76
78
80
82
84
86
88
90+
Speed (mph)
All Vehicles
Trucks
Cars



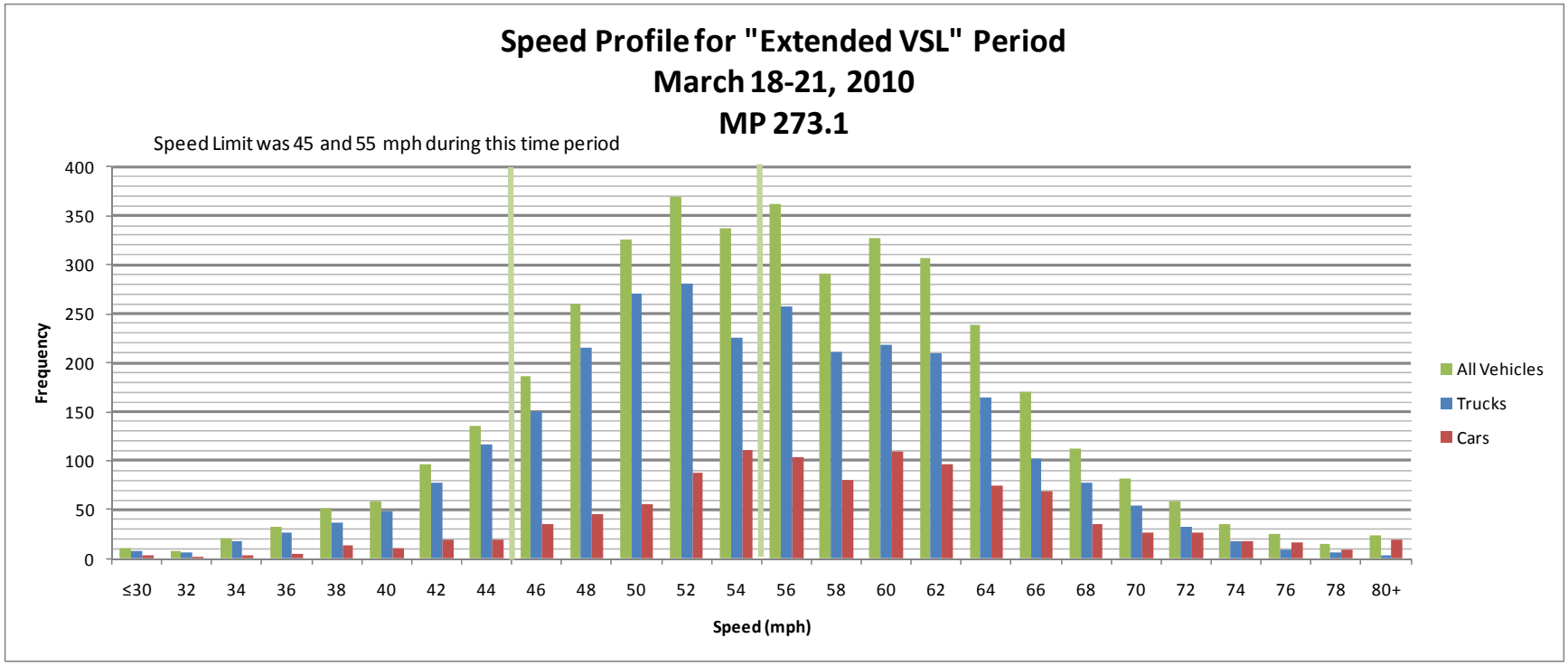
*Note: The road was closed during the "VSL Implemented" period and therefore no data was collected.

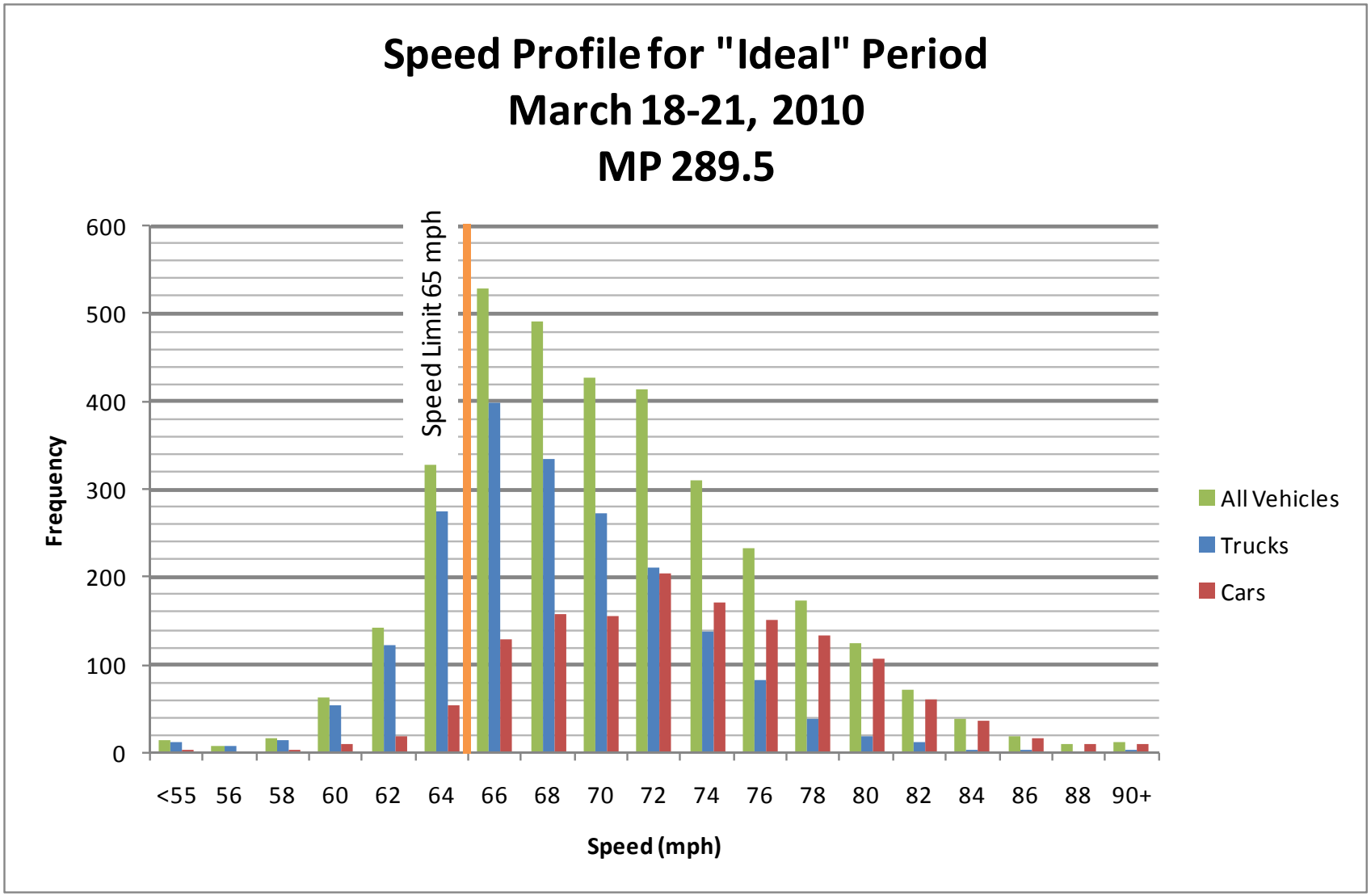

Speed Profile for "Extended VSL" Period
March 18-21, 2010
MP 256.2
Speed Limit was 45 and 55 mph during this time period
Frequency
400
350
300
250
200
150
100
50
0
<35
36
38
40
42
44
46
48
50
52
54
56
58
60
62
64
66
68
70
72
74
76
78
80+
Speed (mph)
All Vehicles
Trucks
Cars


Speed Profile for "Ideal" Period
March 18-21, 2010
MP 273.1
Frequency
600
500
400
300
200
100
0
Speed Limit 65 mph
<55
56
58
60
62
64
66
68
70
72
74
76
78
80
82
84
86
88
90+
Speed (mph)
All Vehicles
Trucks
Cars

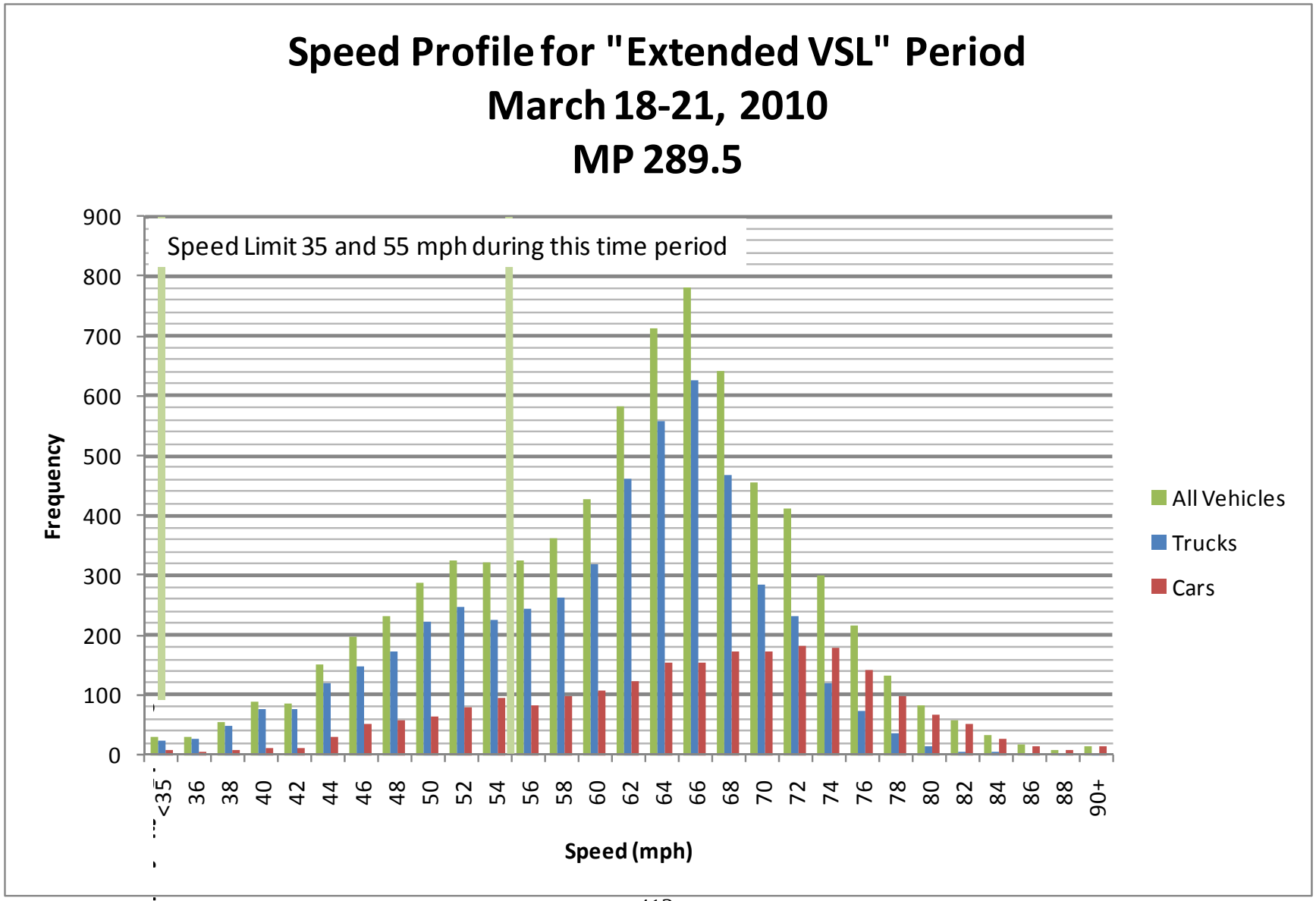


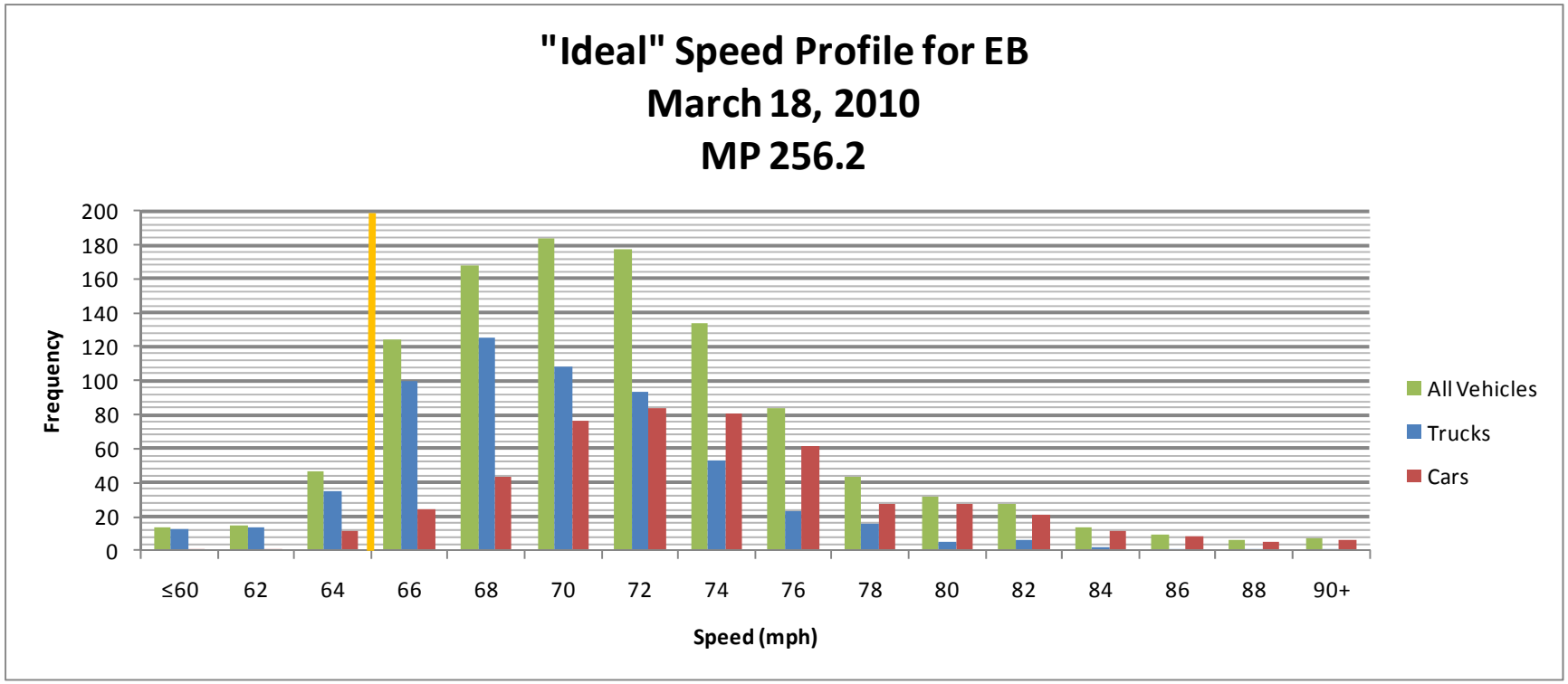
*Note: The road was closed during the "VSL Implemented" period and therefore no data was collected.

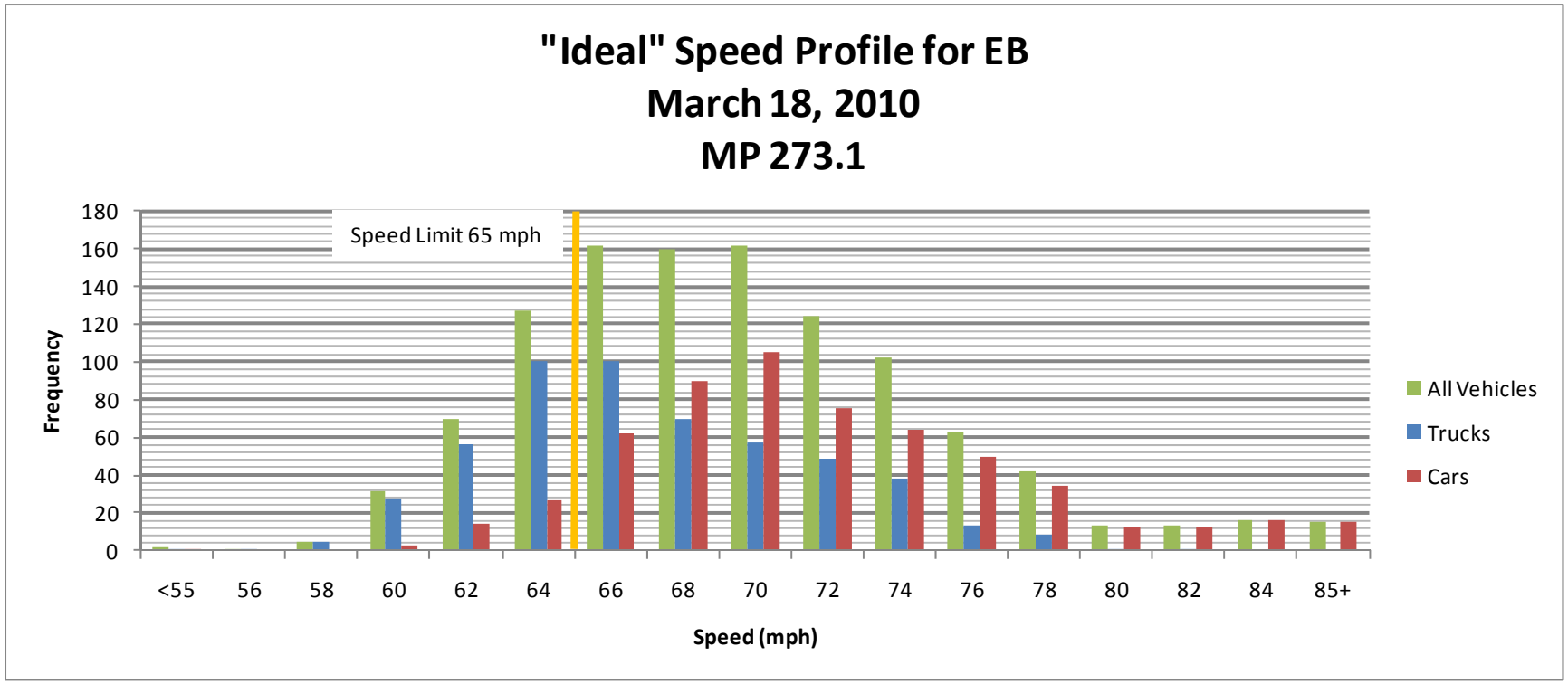

Speed Profile for "Extended VSL" Period
March 18-21, 2010
MP 273.1
Speed Limit was 45 and 55 mph during this time period
Frequency
400
350
300
250
200
150
100
50
0
≤30
32
34
36
38
40
42
44
46
48
50
52
54
56
58
60
62
64
66
68
70
72
74
76
78
80+
Speed (mph)
All Vehicles
Trucks
Cars

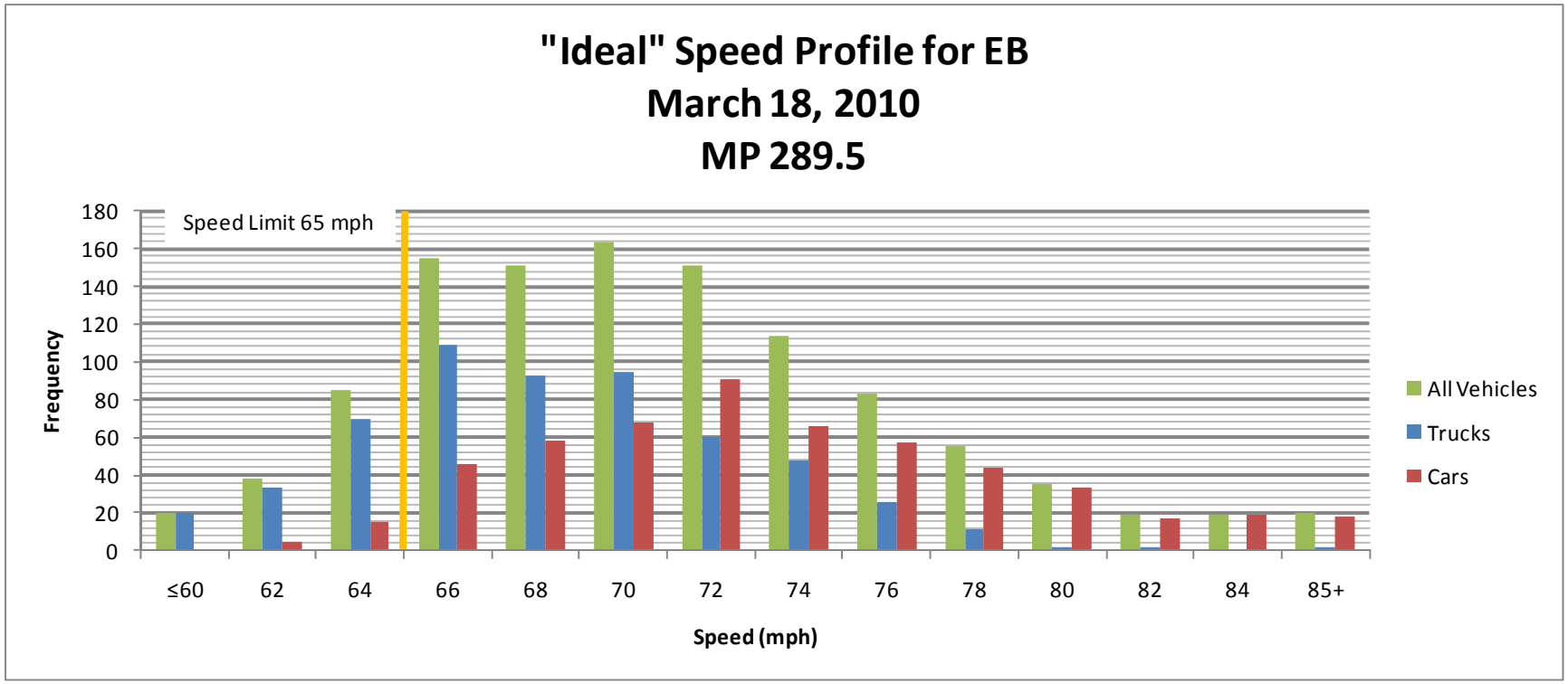


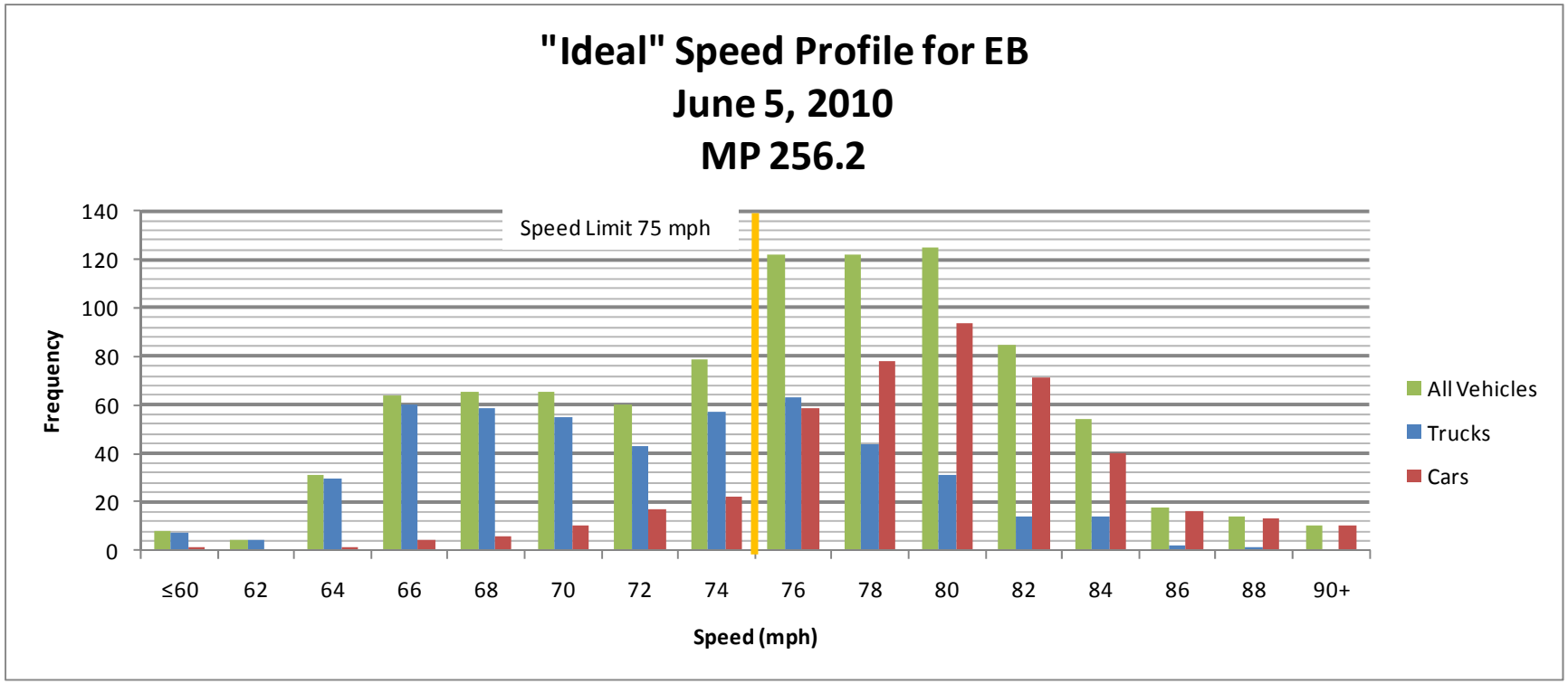
*Note: The road was closed during the "Transition" and "VSL Implemented" periods and therefore no data was collected.

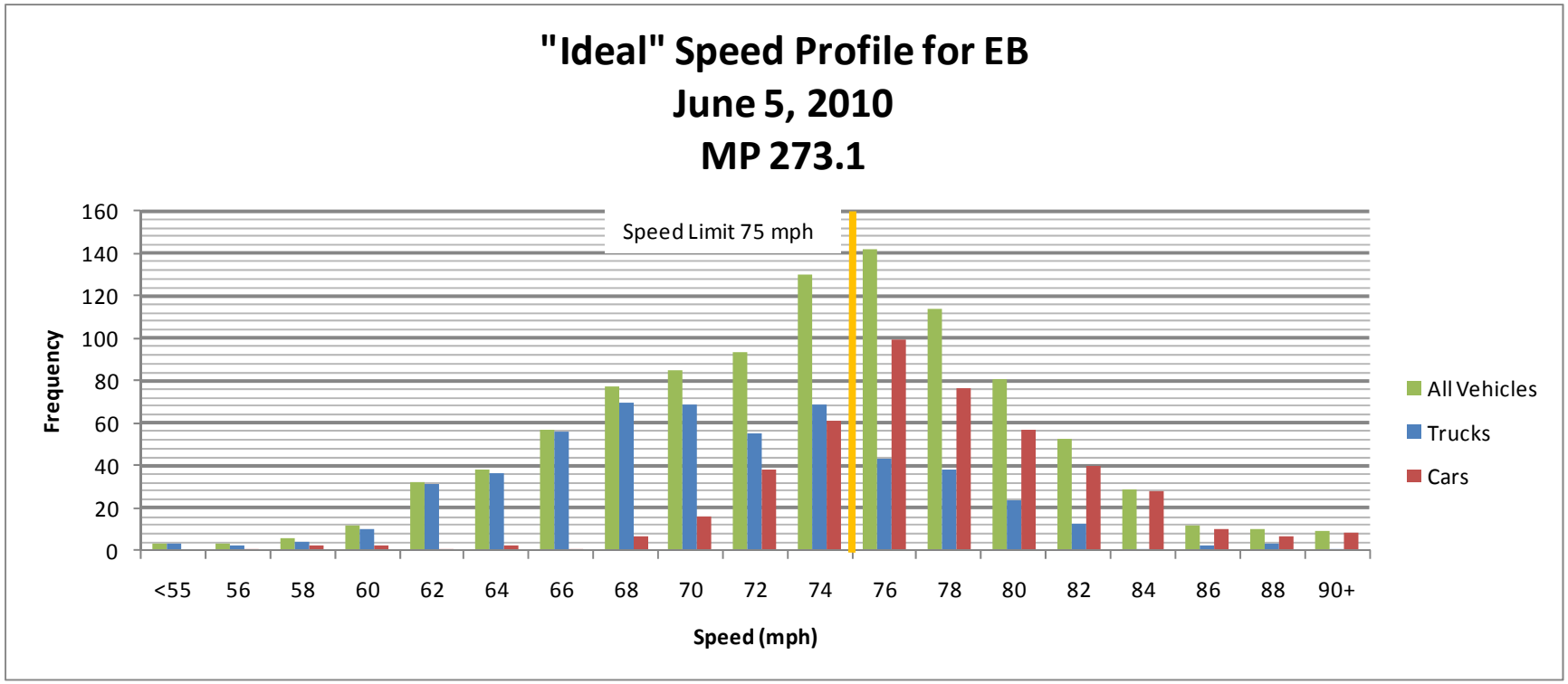

Speed Profile for "Extended VSL" Period
March 18-21, 2010
MP 289.5
Speed Limit 35 and 55 mph during this time period
Frequency
900
800
700
600
500
400
300
200
100
0
<35
36
38
40
42
44
46
48
50
52
54
56
58
60
62
64
66
68
70
72
74
76
78
80
82
84
86
88
90+
Speed (mph)
All Vehicles
Trucks
Cars

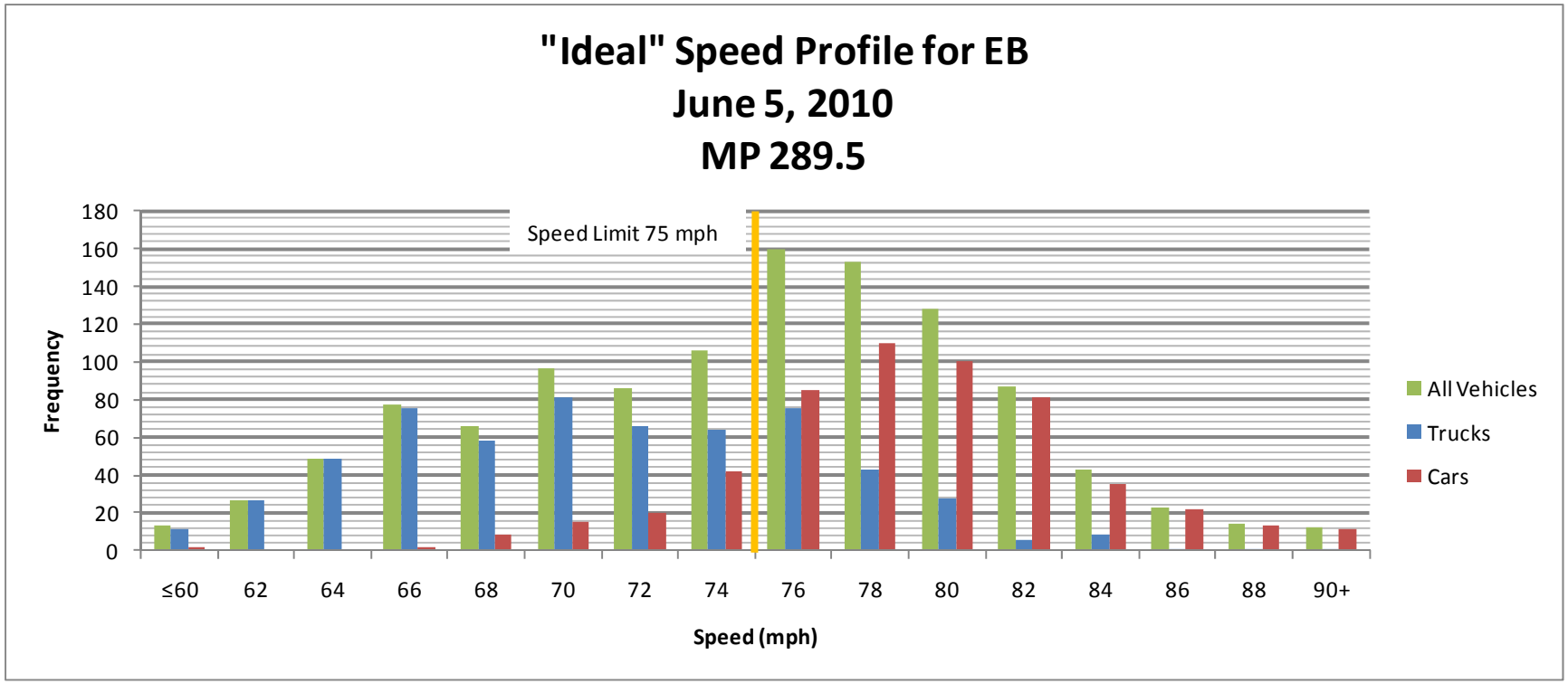

"Ideal" Speed Profile for EB
March 18, 2010
MP 256.2
Frequency
200
180
160
140
120
100
80
60
40
20
0
≤60
62
64
66
68
70
72
74
76
78
80
82
84
86
88
90+
Speed (mph)
All Vehicles
Trucks
Cars


"Ideal" Speed Profile for EB
March 18, 2010
MP 273.1
Speed Limit 65 mph
Frequency
180
160
140
120
100
80
60
40
20
0
<55
56
58
60
62
64
66
68
70
72
74
76
78
80
82
84
85+
Speed (mph)
All Vehicles
Trucks
Cars


"Ideal" Speed Profile for EB
March 18, 2010
MP 289.5
Speed Limit 65 mph
Frequency
180
160
140
120
100
80
60
40
20
0
≤60
62
64
66
68
70
72
74
76
78
80
82
84
85+
Speed (mph)
All Vehicles
Trucks
Cars

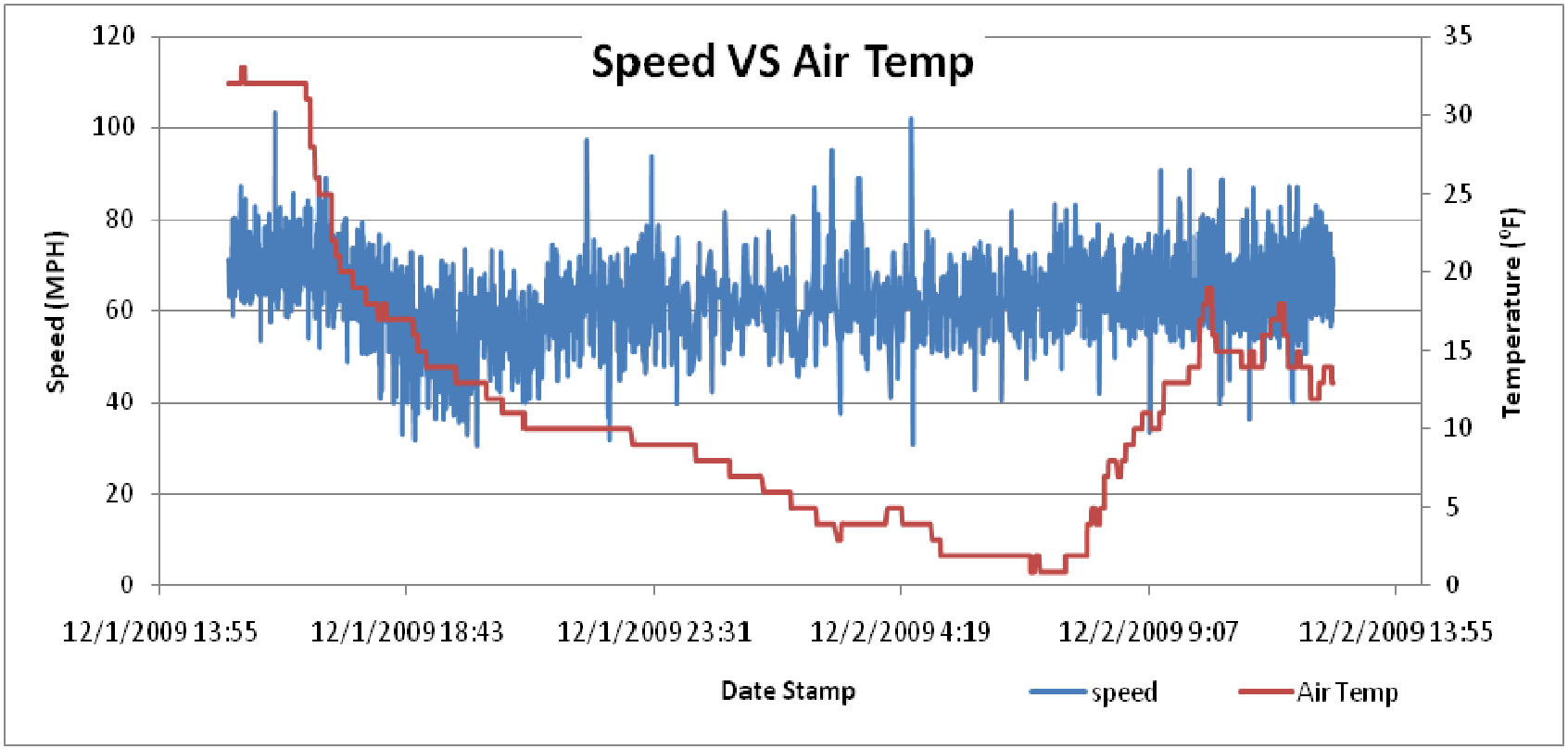

"Ideal" Speed Profile for EB
June 5, 2010
MP 256.2
Speed Limit 75 mph
Frequency
140
120
100
80
60
40
20
0
≤60
62
64
66
68
70
72
74
76
78
80
82
84
86
88
90+
Speed (mph)
All Vehicles
Trucks
Cars

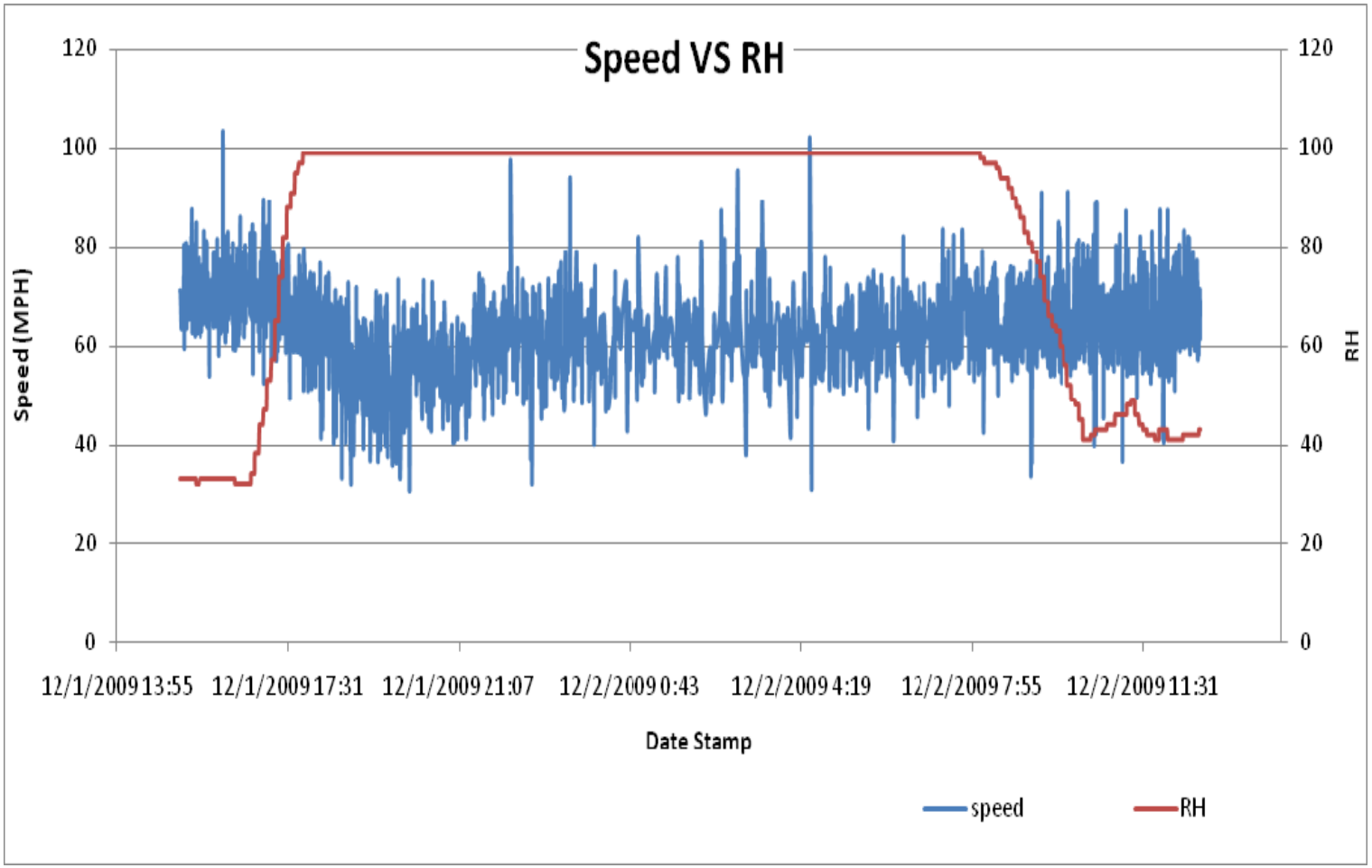

"Ideal" Speed Profile for EB
June 5, 2010
MP 273.1
Speed Limit 75 mph
Frequency
160
140
120
100
80
60
40
20
0
<55
56
58
60
62
64
66
68
70
72
74
76
78
80
82
84
86
88
90+
Speed (mph)
All Vehicles
Trucks
Cars

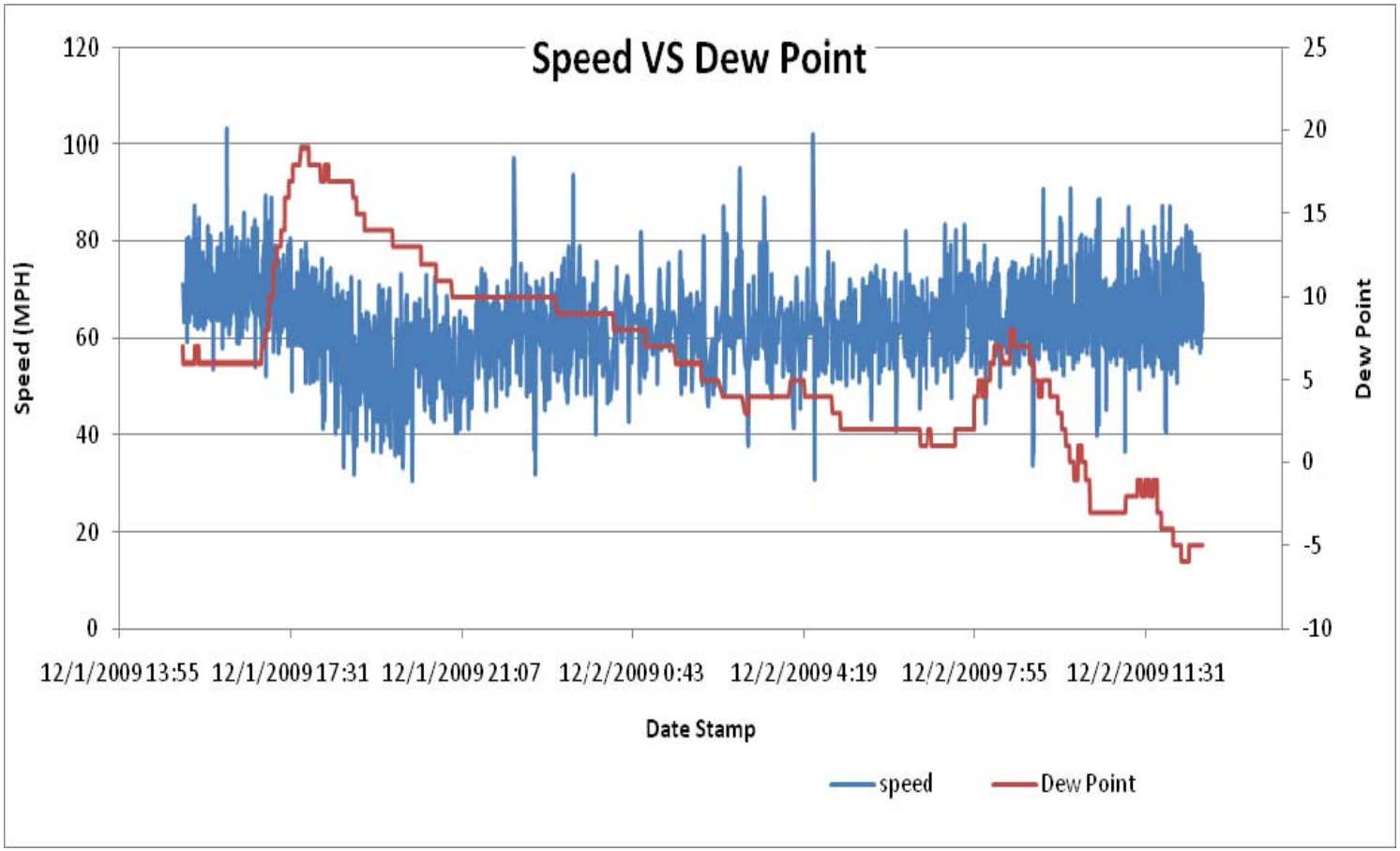

"Ideal" Speed Profile for EB
June 5, 2010
MP 289.5
Speed Limit 75 mph
Frequency
180
160
140
120
100
80
60
40
20
0
≤60
62
64
66
68
70
72
74
76
78
80
82
84
86
88
90+
Speed (mph)
All Vehicles
Trucks
Cars

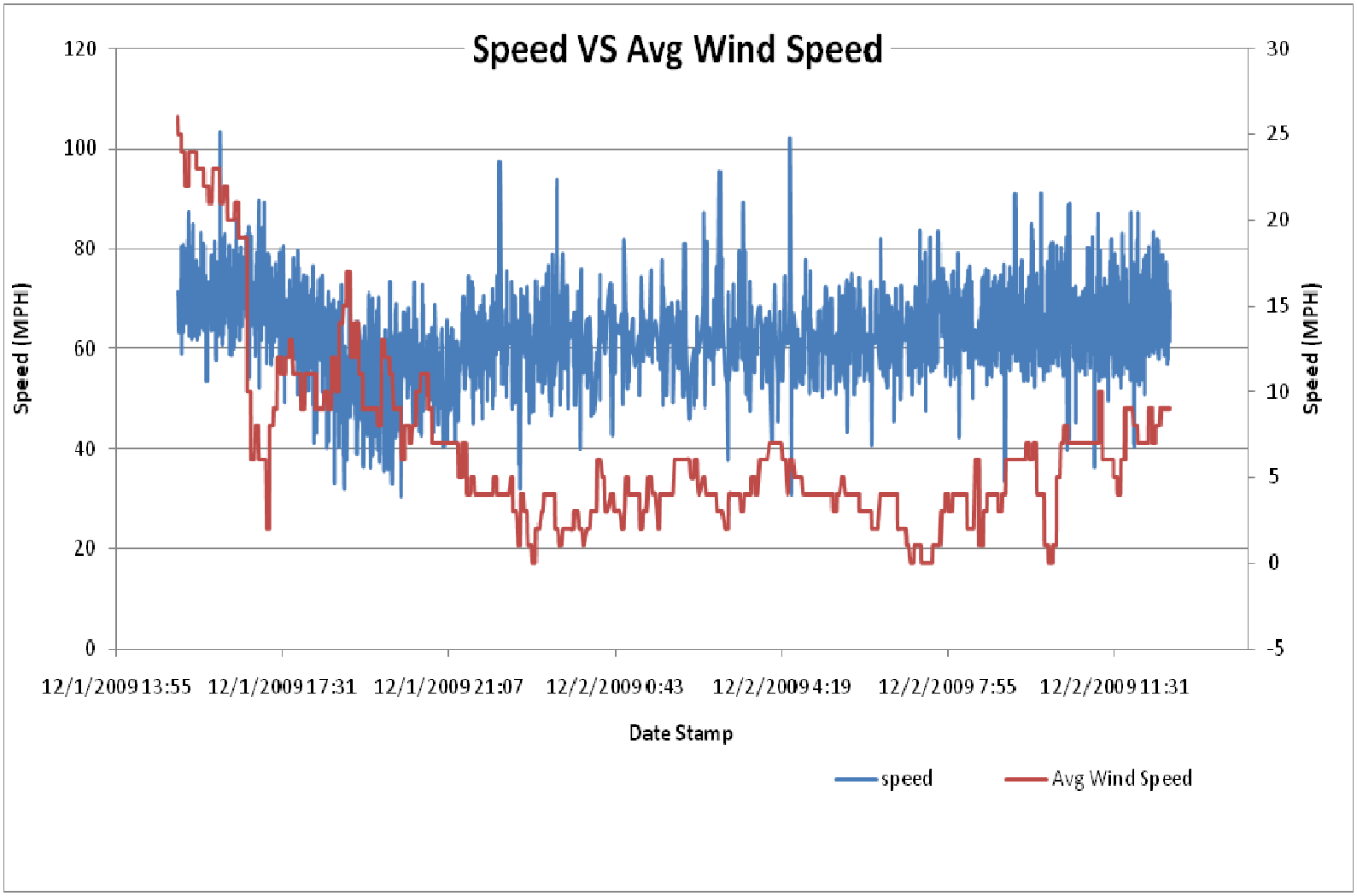
Appendix F

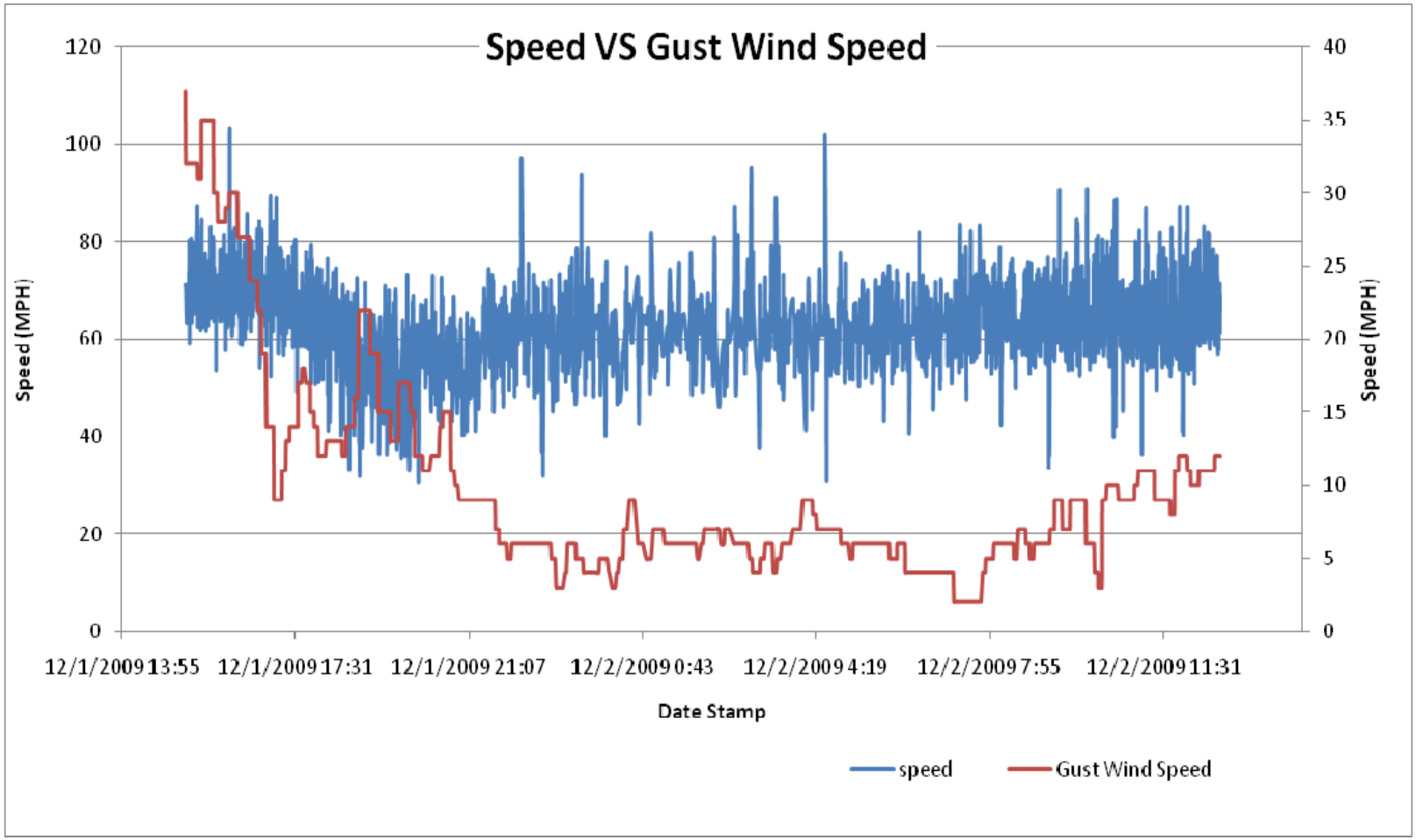
Control Strategy

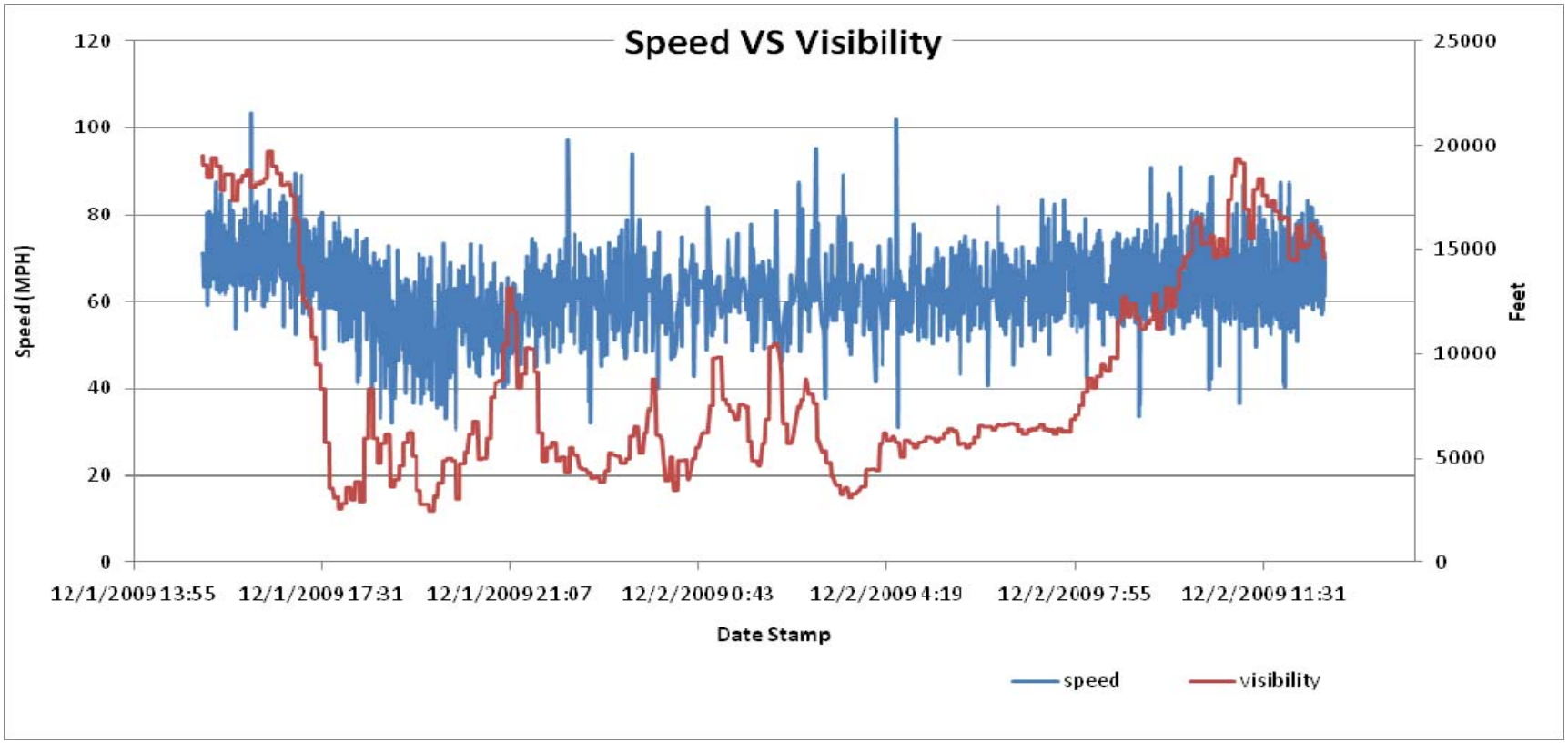

Speed VS Air Temp
Speed (MPH)
Temperature (°F)
120
100
80
60
40
20
0
35
30
25
20
15
10
5
0
12/1/2009 13:55
12/1/2009 18:43
12/1/2009 23:31
12/2/2009 4:19
12/2/2009 9:07
12/2/2009 13:55
Date Stamp
speed
Air Temp

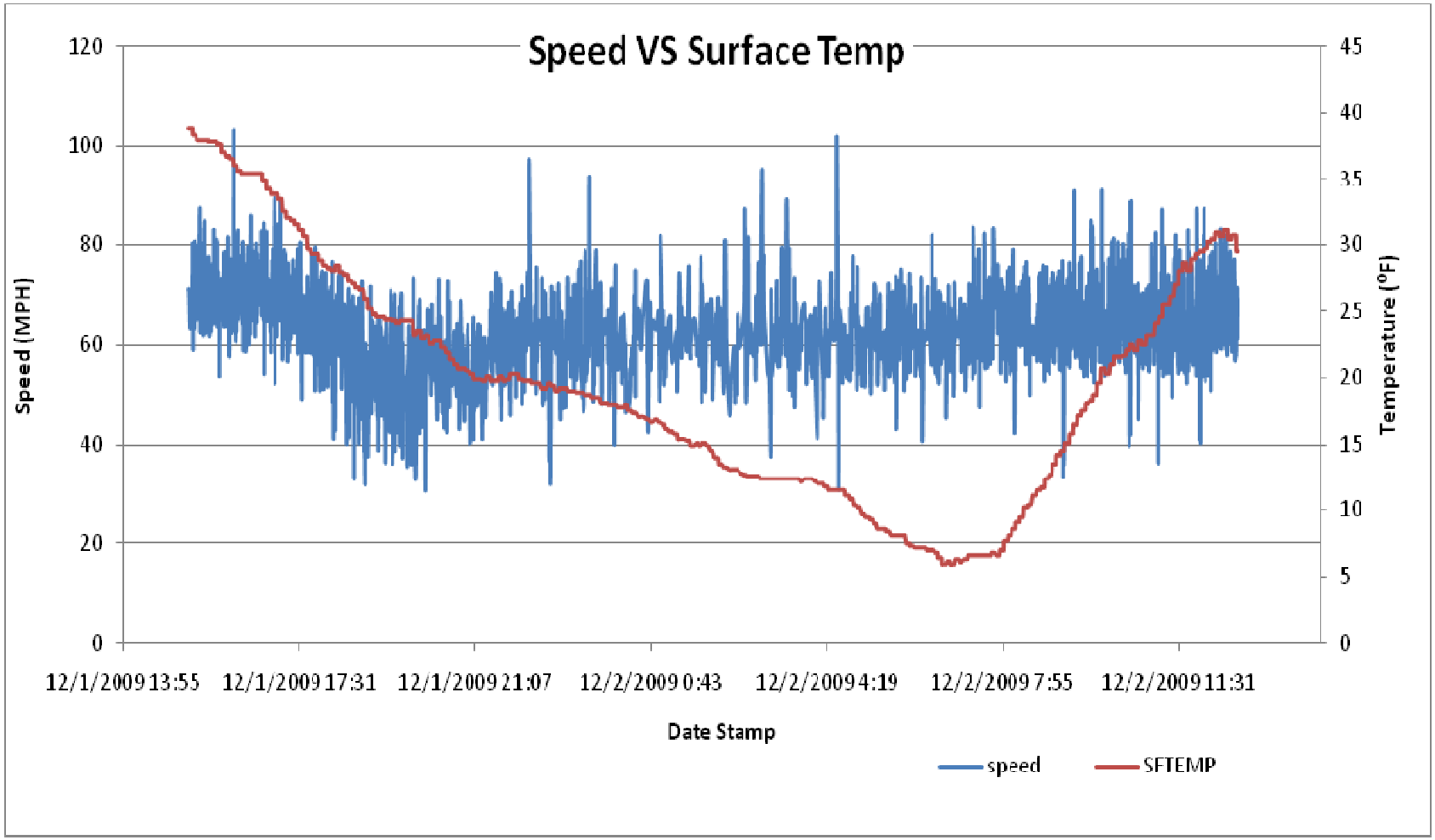

Speed VS RH
120
100
80
60
40
20
0
Speed (MPH)
RH
12/1/2009 13:55
12/1/2009 17:31
12/1/2009 21:07
12/2/2009 0:43
12/2/2009 4:19
12/2/2009 7:55
12/2/2009 11:31
Date Stamp
speed
RH


Speed VS Dew Point
Speed (MPH)
Dew Point
120
100
80
60
40
20
0
25
20
15
10
5
0
-5
-10
12/1/2009 13:55
12/1/2009 17:31
12/1/2009 21:07
12/2/2009 0:43
12/2/2009 4:19
12/2/2009 7:55
12/2/2009 11:31
Date Stamp
speed
Dew Point


Speed VS Avg Wind Speed
120
100
80
60
40
20
0
30
25
20
15
10
5
0
-5
Speed (MPH)
Speed (MPH)
12/1/2009 13:55
12/1/2009 17:31
12/1/2009 21:07
12/2/2009 0:43
12/2/2009 4:19
12/2/2009 7:55
12/2/2009 11:31
Date Stamp
speed
Avg Wind Speed


Speed VS Gust Wind Speed
Speed (MPH)
120
100
80
60
40
20
0
40
35
30
25
20
15
10
5
0
Speed (MPH)
12/1/2009 13:55
12/1/2009 17:31
12/1/2009 21:07
12/2/2009 0:43
12/2/2009 4:19
12/2/2009 7:55
12/2/2009 11:31
Date Stamp
speed
Gust Wind Speed


Speed VS Visibility
Speed (MPH)
Feet
Date Stamp
120
100
80
60
40
20
0
25000
20000
15000
10000
5000
0
12/1/2009 13:55
12/1/2009 17:31
12/1/2009 21:07
12/2/2009 0:43
12/2/2009 4:19
12/2/2009 7:55
12/2/2009 11:31
speed
visibility


Speed VS Surface Temp
Speed (MPH)
Temperature (°F)
120
100
80
60
40
20
0
45
40
35
30
25
20
15
10
5
0
12/1/2009 13:55
12/1/2009 17:31
12/1/2009 21:07
12/2/2009 0:43
12/2/2009 4:19
12/2/2009 7:55
12/2/2009 11:31
Date Stamp
speed
SFTEMP