Results from the Integrated Mobile Observations Study

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Final Report — May 30, 2013

FHWA-JPO-13-066

Image courtesy of Minnesota DOT (http://www.newsline.dot.state.mn.us/images/10/feb/Snowplow600.jpg)

U.S. Department of Transportation

Produced by DTFH61-08-D-00012
ITS Joint Program Office
Research and Innovative Technology Administration
U.S. Department of Transportation

Notice

Technical Report Documentation Page

1. Report No. **FHWA-JPO-13-066**	**2. Government Accession No.**		**3. Recipient's Catalog No.**
4. Title and Subtitle Concept of Operations for the Use of Connected Vehicle Data in Road Weather Applications			**5. Report Date** May 30, 2013
			6. Performing Organization Code
7. Author(s) Michael Chapman, Sheldon Drobot, Amanda Anderson and Crystal Burghardt			**8. Performing Organization Report No.**
9. Performing Organization Name And Address University Corporation for Atmospheric Research National Center for Atmospheric Research 3090 Center Green Dr. Boulder, CO 80301			**10. Work Unit No. (TRAIS)**
			11. Contract or Grant No. DTFH61-08-D-00012
12. Sponsoring Agency Name and Address United States Department of Transportation Research and Innovative Technology Administration Federal Highway Administration, Office of Operations 1200 New Jersey Ave., SE Washington, DC 20590			**13. Type of Report and Period Covered**
			14. Sponsoring Agency Code FHWA, HOTO
15. Supplementary Notes Mr. Gabriel Guevara (GTM)			
16. Abstract With funding and support from the USDOT RITA and direction from the FHWA Road Weather Management Program, NCAR is developing a Vehicle Data Translator (VDT) software system that incorporates vehicle-based measurements of the road and surrounding atmosphere with other weather data sources. The purpose of this document is to provide a short overview of the VDT software, a description of several possible applications for key potential end-users of the VDT, and a description of the data standards that are required in order for the mobile weather data to be useful for various road weather impact applications.			
17. Key Words Connected vehicles, road weather, probe data	**18. Distribution Statement** This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.		
19. Security Classif. (of this report) Unclassified	**20. Security Classif. (of this page)** Unclassified	**21. No. of Pages** 157	**22. Price** **$0.00**

m DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

Acknowledgements

This work is sponsored by the U.S. Department of Transportation Road Weather Management Program and the Intelligent Transportation Systems Joint Program Office under contract DTH61-08-D-00012.

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Acronyms

ABS	Anti-lock Braking System
CAN	Controller Area Network
DTE09	2009 Development Test Environment Experiment
DTE10	2010 Development Test Environment Experiment
FHWA	Federal Highway Administration
GPS	Global Positioning System
IMO	ITS Mobile Observations Study
ITS	Intelligent Transportation Systems
MD	Mean Difference
MAD	Mean Absolute Difference
MAE	Mean Absolute Error
MNDOT	Minnesota Department of Transportation
MSL	Mean Sea Level
NCAR	The National Center for Atmospheric Research
NDOT	Nevada Department of Transportation
OBD-II	On-board Diagnostic
PGN	Parameter Group Number
RITA	Research and Innovative Technology Administration
RWIS	Road Weather Information System
SPN	Suspect Parameter Number
USDOT	U.S. Department of Transportation
UTC	Coordinated Universal Time
VDT	Vehicle Data Translator

Executive Summary

The U.S. Department of Transportation's (USDOT) Federal Highway Administration (FHWA) and Research and Innovative Technology Administration (RITA) are jointly working to promote safety, mobility, and the environment on the nation's surface transportation system through a new connected vehicle initiative. This initiative is a multimodal effort to enable wireless communications among vehicles, the infrastructure, and passengers' personal communication devices. It will enhance Americans' safety, mobility, and quality of life, while helping to reduce the environmental impact of surface transportation.

The purpose of this document is to provide a summary of the data collection efforts for the ITS Mobile Observations (IMO) study, the results of the analysis of the quality of those observations, and results of the incorporation of the observations into road weather and/or road maintenance specific applications.

The major findings in this report are:

- The external sensors used in the IMO closely-matched and were well-correlated with the nearby RWIS stations.
- The NDOT CANbus data are not currently of a very high quality, although the barometric pressure may be reasonable given uncertainties in elevation and the coarse reporting resolution.
- The DOCS CANbus air temperature data closely correlated with the nearest RWIS stations.
- The observations analyzed along VDT segments show overall close similarity with the individual observation points along these segments, leading to the conclusion that VDT segments are generally representative of what is being observed.
- Mn/DOT latency varies substantially based on day, from a low of 0% to a high of 100%.
- Early indications are that NDOT latency varies substantially based on day, from a low of 0% to a high of about 20%.
- Overall, there is a consistently strong correspondence between the VDT analysis of surface temperature and what is being observed at RWIS stations. Although this correspondence cannot prove irrefutably that the VDT output would have significant value if used to forecast pavement temperatures away from RWIS sites, it is a promising result.
- Data from DOCS were useful in analysis of the VDT Stage III algorithms and have provided guidance for algorithm development.

Chapter 1 Introduction

The U.S. Department of Transportation's (USDOT) Federal Highway Administration (FHWA) and Research and Innovative Technology Administration (RITA) are jointly working to promote safety, mobility, and the environment on the nation's surface transportation system through a new connected vehicle initiative. This initiative is a multimodal effort to enable wireless communications among vehicles, the infrastructure, and passengers' personal communication devices. It will enhance Americans' safety, mobility, and quality of life, while helping to reduce the environmental impact of surface transportation.

During 2011 and 2012, the Intelligent Transportation Systems (ITS) Mobile Observations (IMO) study was conducted in collaboration with the Nevada and Minnesota State Departments of Transportation (NDOT and MNDOT, respectively) as well as the National Center for Atmospheric Research (NCAR). The purpose of the study was to partner with the states in order to demonstrate how weather, road condition, and other related vehicle data might be collected, transmitted, processed, and used for decision support applications and activities.

Another goal of the study was to provide data to NCAR that will enable the enhancement of the capabilities of the Vehicle Data Translator (VDT), which meshes native (and non-native) weather-related vehicle observations with traditional weather data (e.g., radar, satellite, fixed weather stations) in order to quality check the observations and generate road and/or atmospheric hazard products for a variety of end users.

The purpose of this report is to provide a summary of the data collection efforts by the states and from a field study with one vehicle, which was conducted by NCAR, provide results and analysis of the quality of the observations from the data collection efforts, and provide results and discussion of the utilization of the vehicle observations into road weather or maintenance-related applications.

Chapter 2 Data Collection

Minnesota

Data were logged from 6 December 2011 through 27 February 2012. The number of time-stamped observations received per day is illustrated in Figure 1. There were relatively few Controller Area Network (CAN) messages logged in December and early January, with the majority being collected after 15 January.

Appendix A includes the comprehensive project report from Minnesota. Table 1 lists the number of observations per Parameter Group Number (PGN), as well as the dates spanned by these observations, including the data with invalid PGNs. The descriptions of the PGNs, and related Suspect Parameter Numbers (SPNs), are listed in Appendix B. There were relatively few of these invalid PGNs. In the real-time data, all invalid PGNs occurred before the logging period began. About 13% of the total observations had invalid “null” timestamps or otherwise incorrectly formatted or had invalid timestamps.

There were occasional inaccurate Global Positioning System (GPS) location reports. Most of these were from incorrect formatting issues. For example, of the inaccurate numbers, many appeared to be missing the beginning or ending numbers of the location stamp, or were missing a decimal point (e.g., latitude 4506 was likely supposed to be 45.06). Many other values were incorrectly formatted with double decimal points (e.g., 48.348.3), double negative signs (e.g., -95.1-95.), or some variation of “null” (including null, nnull, nul, and nulull among others). These “null” and incorrectly formatted data made up 12.4% of latitude and longitude pairs. Of the non-missing latitude and longitude pairs, less than 0.01% were deemed to be not reasonably near Minnesota.

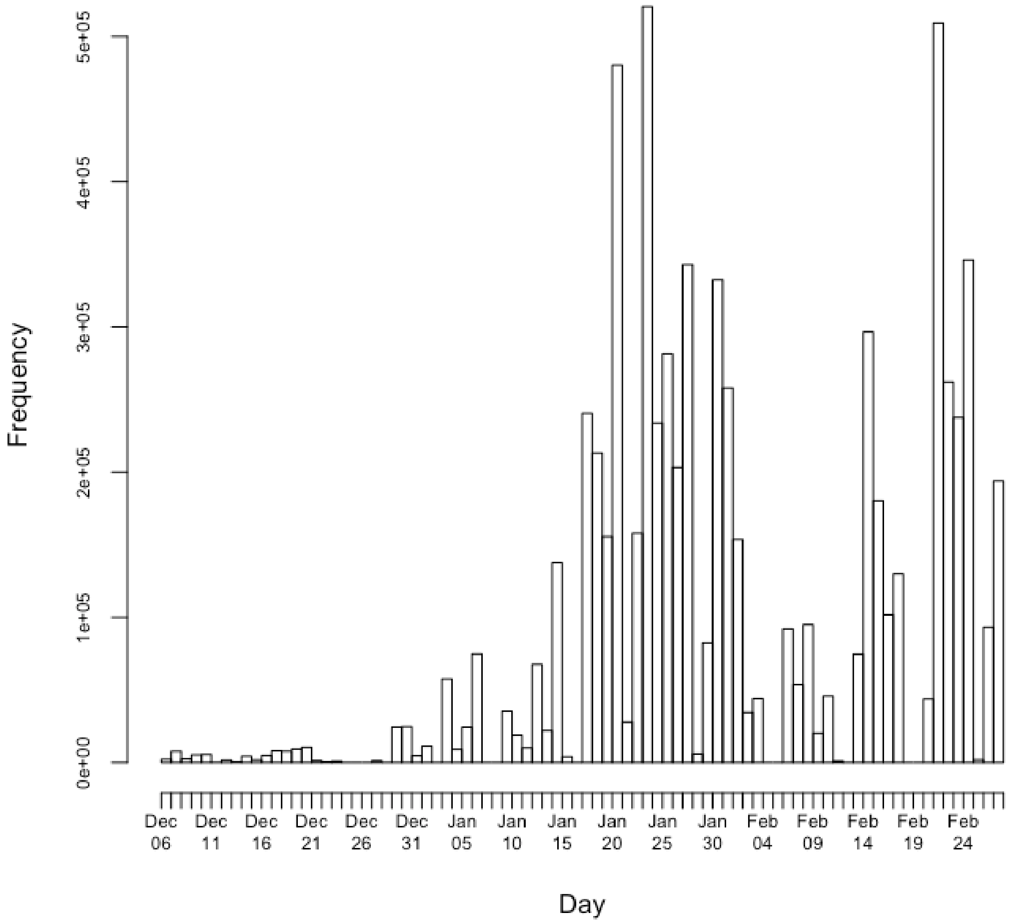


Figure 1. Number of CAN messages logged per day over the summary period (6 December 2011 – 27 February 2012) (Image courtesy of UCAR).

Table 1. Number of observations logged for each PGN category (Table courtesy of NCAR).

PGN	# Obs	Date Start	Date End
61441	325,546	7 Dec 2011	27 Feb 2012
61442	2,996,721	7 Dec 2011	27 Feb 2012
61443	625,595	7 Dec 2011	27 Feb 2012
61444	2,850,388	7 Dec 2011	27 Feb 2012
61445	313,786	7 Dec 2011	27 Feb 2012
61469	0	n/a	n/a
61482	0	n/a	n/a
61485	0	n/a	n/a
64773	0	n/a	n/a
64776	0	n/a	n/a
64777	0	n/a	n/a
64851	0	n/a	n/a
64870	0	n/a	n/a
64972	2,286	11 Jan 2012	27 Feb 2012
64973	0	n/a	n/a
64992	0	n/a	n/a
65031	0	n/a	n/a
65088	0	n/a	n/a
65100	0	n/a	n/a
65134	0	n/a	n/a
65171	0	n/a	n/a
65191	0	n/a	n/a
65215	147,859	7 Dec 2011	27 Feb 2012
65217	26,048	7 Dec 2011	27 Feb 2012
65237	0	n/a	n/a
65248	133,525	7 Dec 2011	27 Feb 2012
65253	192	11 Jan 2012	27 Feb 2012
65255	5,892	13 Dec 2011	27 Feb 2012
65260	0	n/a	n/a
65261	2,353	7 Dec 2011	21 Jan 2012
65262	22,328	8 Dec 2011	27 Feb 2012
65263	51,937	9 Dec 2011	27 Feb 2012
65265	375,825	7 Dec 2011	27 Feb 2012
65266	274,731	7 Dec 2011	27 Feb 2012
65269	14,535	14 Dec 2011	27 Feb 2012
65271	25,589	7 Dec 2011	27 Feb 2012
65272	26,427	7 Dec 2011	27 Feb 2012
Invalid	77	3 Jan 2012	27 Feb 2012

Vehicle Parameters

ABS (Anti-lock Braking System)

The ABS parameter output is categorized as follows: 0 (passive), 1 (active), 2 (reserve). ABS was activated very few times (32 of 159621) during the analyzed period (Figure 2).

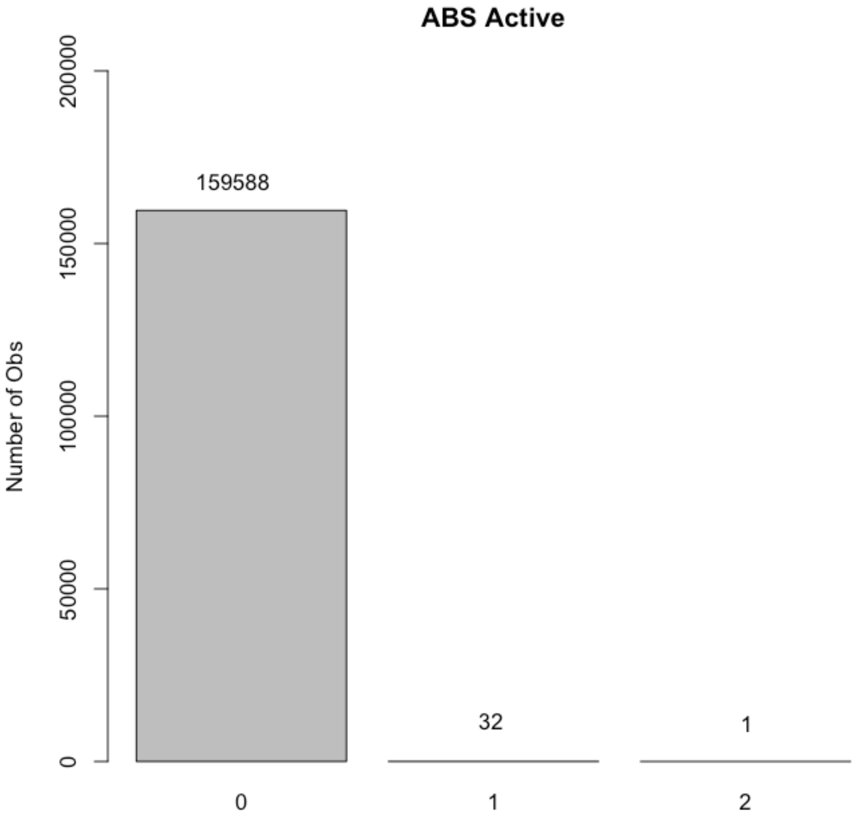


Figure 2. Bar plot of number of ABS observations by category (Image courtesy of NCAR).

Wheel Speed

The wheel speed category contained two main observations: the front axle speed and the relative speed of each wheel. Most of the points appeared reasonable (Figure 3 and Figure 4). For Front Axle Speed, only 0.002% of the observations were unreasonable, the majority of these being value 255. For the relative wheel speeds, several values are capped at -7.812 and 8.125, and 35% of observations matched one of those values.

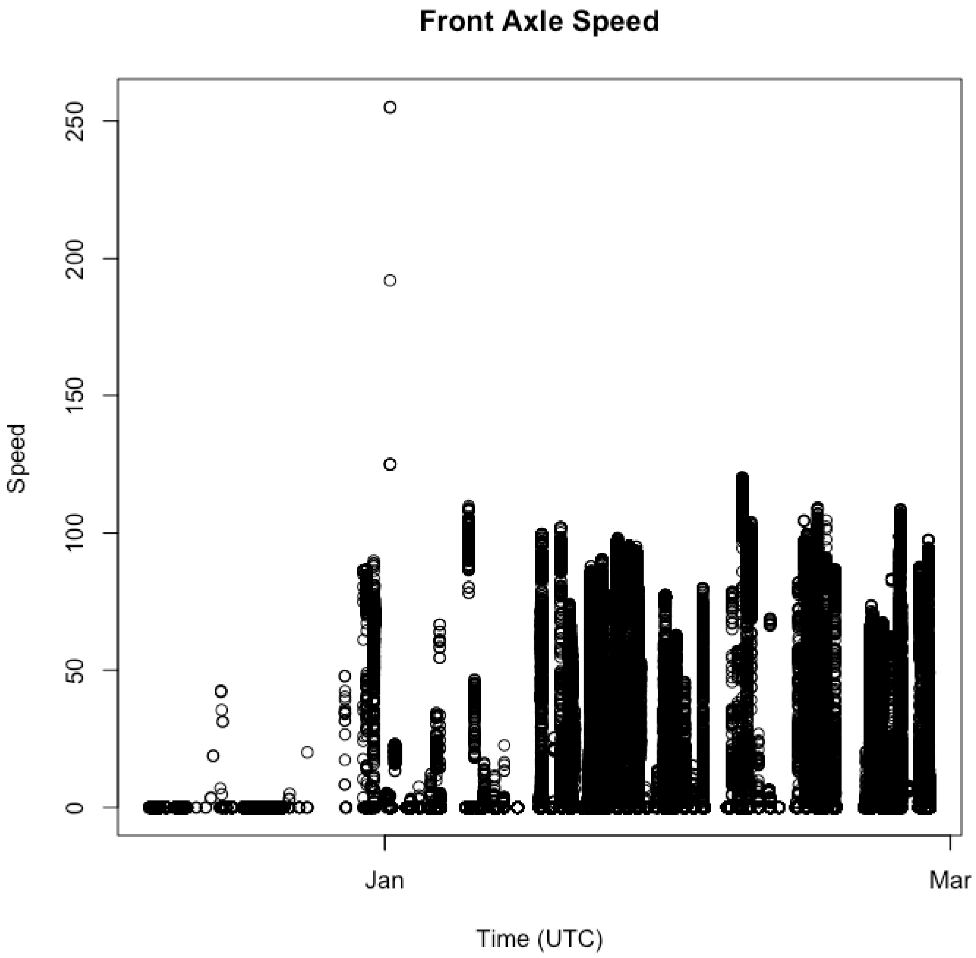


Figure 3. Time series of front axle speed observations (Image courtesy of NCAR).

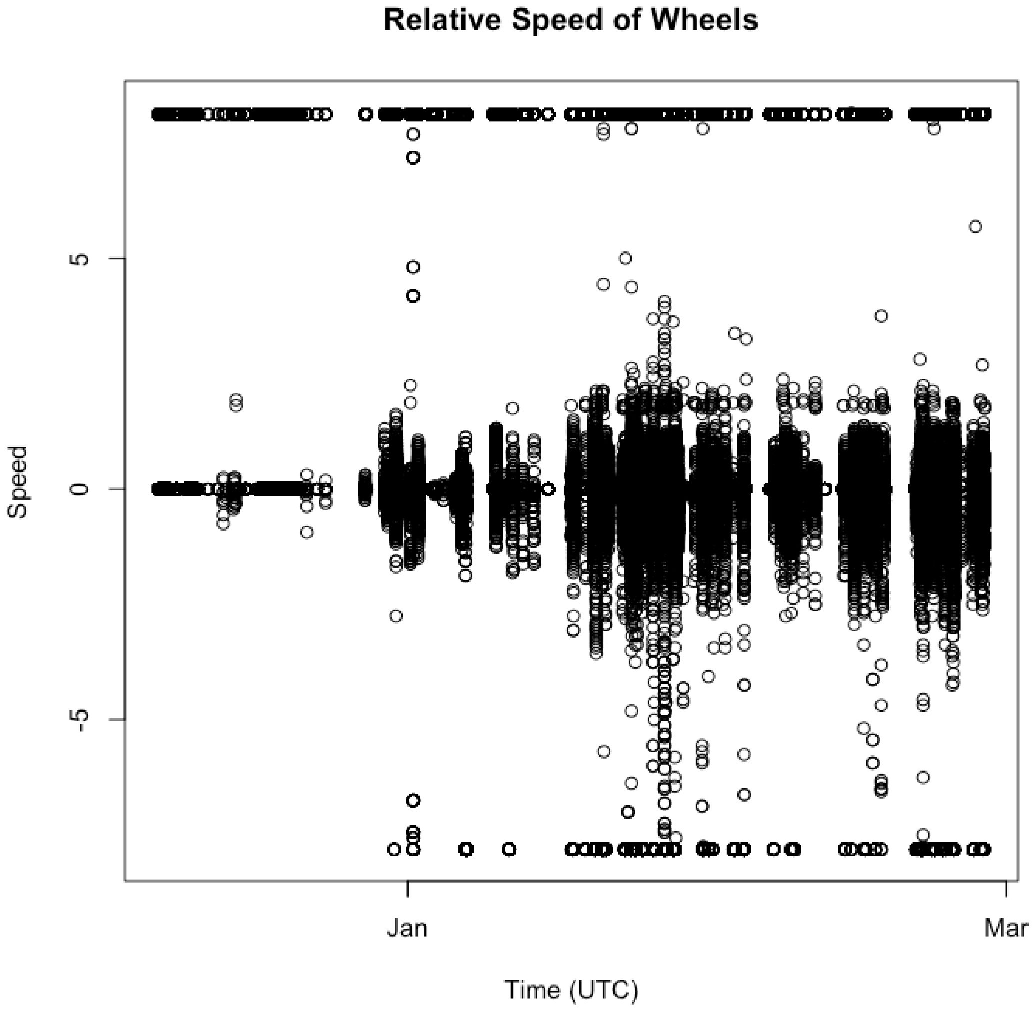


Figure 4. Time series of relative wheel speed observations (Image courtesy of NCAR).

Cruise Control and Vehicle Speed

There were over 300,000 (over 95%; Figure 5) of the observations for cruise control that were 0 (passive) and less than 5% that were 1 (active). There were also two additional settings that were not defined or observed in the real-time data: 5 and 102. Some speed observations were reported as 256 (6.2%), the others were reasonable (Figure 6) except for one value of 25875.

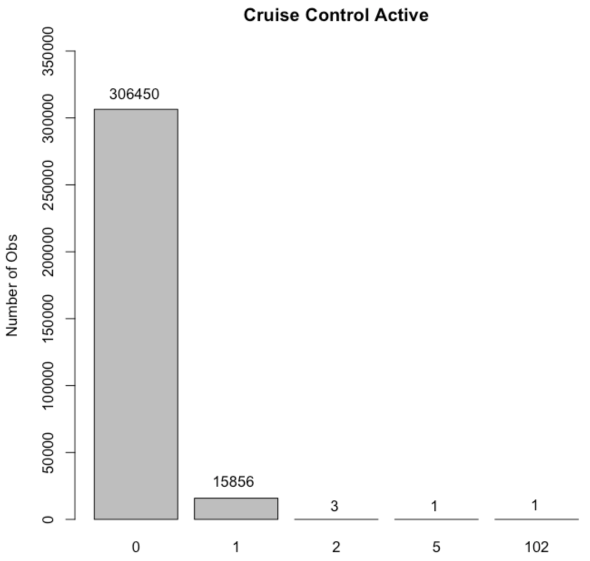


Figure 5. Bar plot of number of cruise control observations by category (Image courtesy of NCAR).

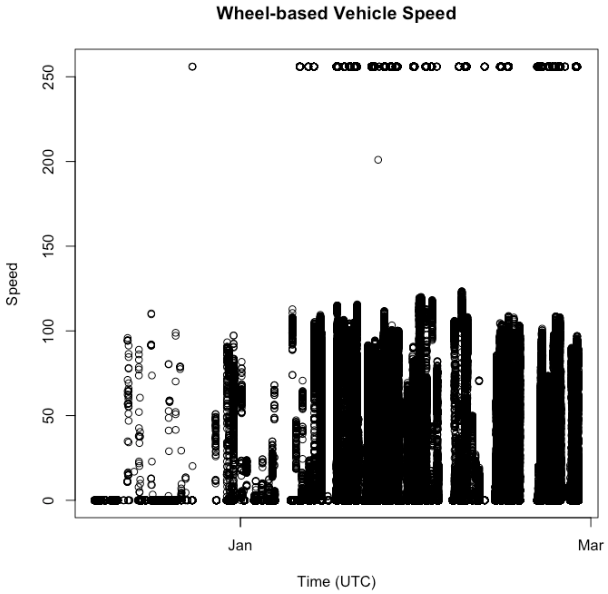


Figure 6. Time series of wheel-based vehicle speed observations (Image courtesy of NCAR).

Ambient Conditions

The two important meteorological variables in the ambient conditions group were barometric pressure and ambient air temperature.

The barometric pressure was reported at a 5 hPa (0.5 kPa) resolution. Unreasonable values included 0 and 1275 hPa for 1.6% of the observations. Otherwise, all observations were between 930 and 1020 hPa. A time series of barometric pressure with outliers removed is shown in Figure 7.

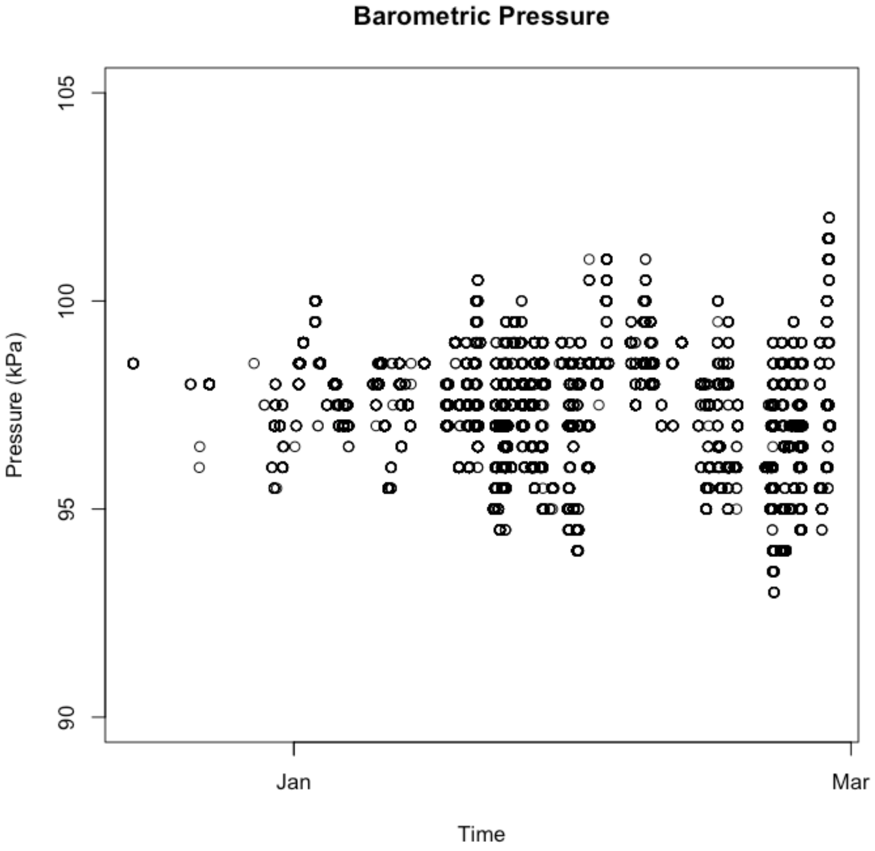


Figure 7. Time series of barometric pressure observations with outliers removed (Image courtesy of NCAR).

The ambient air temperature was reported at a variable resolution with decimal place out to 0.001 K. Unreasonable values of 0 and 2047.969 were reported 68% of the time. Otherwise, observations were slightly more reasonable between -16.312°C and 44°C, although the higher values may be found unreasonably warm when compared to ground stations. A time series of ambient air temperature with outliers removed is shown in Figure 8.

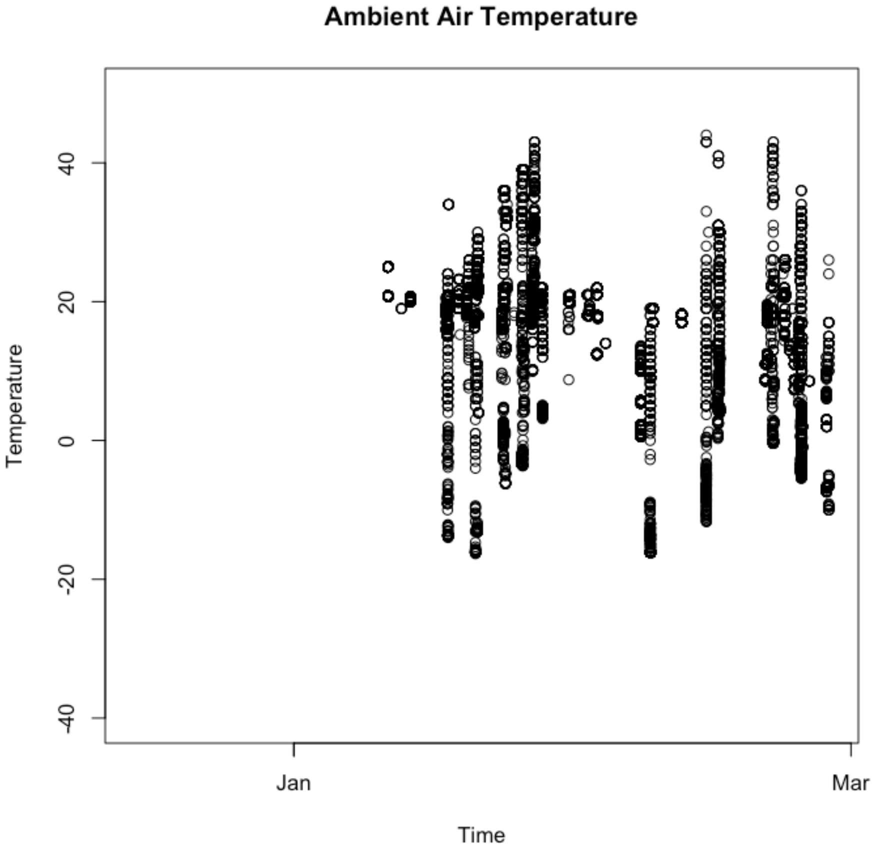


Figure 8. Time series of air temperature observations with outliers removed (Image courtesy of NCAR).

Nevada

The following summary covers the observations received from the NDOT via CANbus and external sensor (e.g., Surface Patrol HD or RoadWatch sensors) depending on the vehicle. The data were received in the format of an ascii table listing the observation time, location, air temperature, barometric pressure, speed, and brake status. Data were received from May 2011 through April 2012, non-inclusive. The number of time-stamped observations received per day is illustrated in Figure 9. The number of CAN messages varied during the summer and early fall of 2011, and messages were not received for every day. There was a void in CAN messages through late October and November, starting up again in December. The number of CAN messages peaked in mid to late January and again in mid February before considerably increasing through March and early April. The number of CAN messages received also varied by vehicle (Figure 10) and some vehicles reported only “no data” in their CAN messages (Figure 11).

There were occasional inaccurate GPS location reports. Several of these were a 0° or near-0° latitude or longitude, but were not limited to this number (including values in the 1000s). Of all the latitude and longitude pairs, about 1.3% were not reasonably located near Nevada. Table 2 is a listing of the CANbus parameters, number of observations of each parameter and the start and end date in the data set.

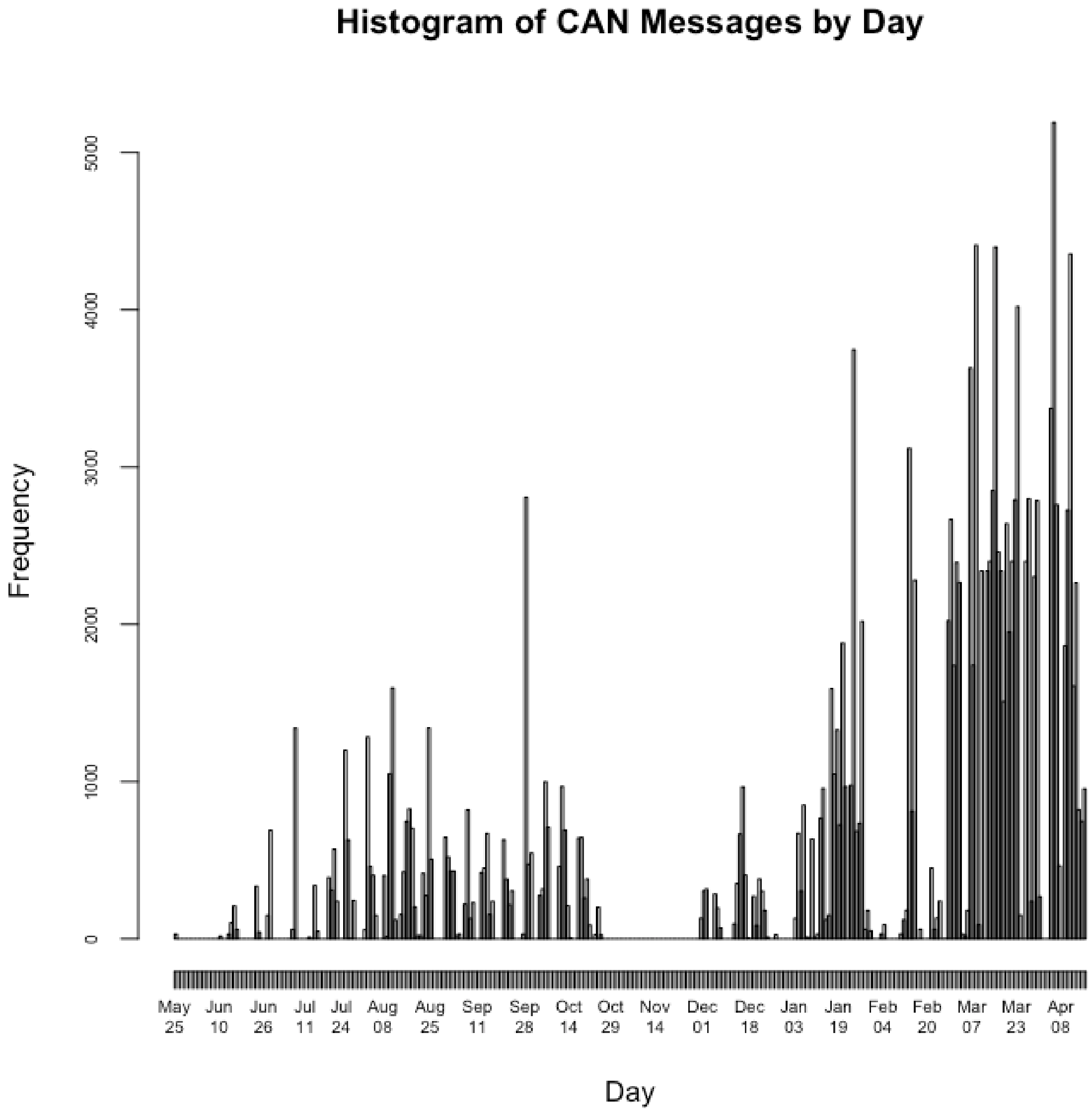


Figure 9. Time Series of number of CAN messages per day over the summary period (Image courtesy of NCAR).

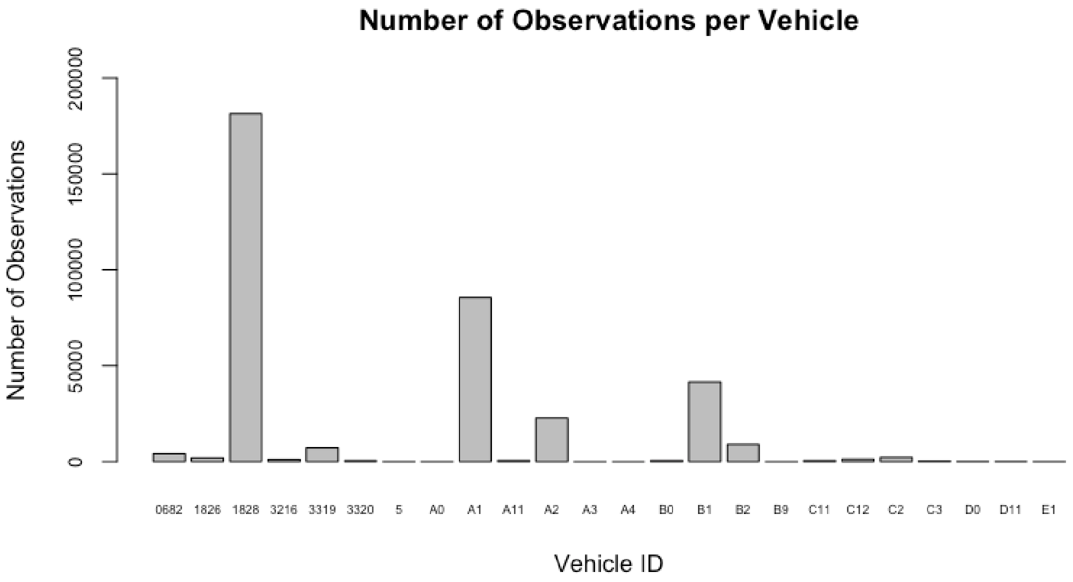


Figure 10. Number of CAN messages received per vehicle over the summary period (Image courtesy of NCAR).

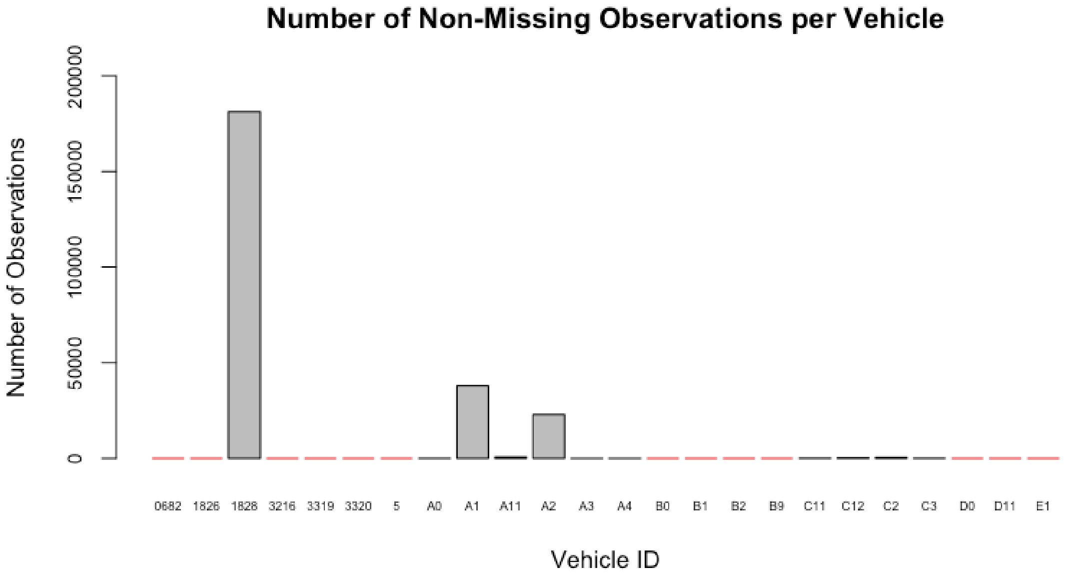


Figure 11. Number of non-missing CAN messages received per vehicle over the summary period. Vehicles that had zero non-missing observations are marked in red (Image courtesy of NCAR).

Table 2. Listing of CANbus observation parameters including counts, and begin and end dates (Table courtesy of NCAR).

Observation	# Obs	Date Start	Date End
Latitude	162,837	25 May 2011	16 April 2012
Longitude	162,837	25 May 2011	16 April 2012
Elevation	1,561	7 July 2011	18 March 2012
Speed	162,837	25 May 2011	16 April 2012
Brake Status	n/a	n/a	n/a
Intake Air Temperature	46,625	7 July 2011	16 April 2012
Barometric Pressure	46,625	7 July 2011	16 April 2012
Outer sensor – Air Temperature	24,555	25 May 2011	16 April 2012
Outer sensor – Surface Temperature	126,162	25 May 2011	16 April 2012

Vehicle Parameters

Speed

Speed was reported in m/s at 0.00001 resolution. There were several unreasonable values in the 100s and 1000s up to 8480 m/s. The majority of the speeds were reported as 0 m/s. Of the total reported speeds, 60% were reported as exactly 0 m/s and 1.1% were reported as over 50 m/s (111 mph). The distribution of reasonable speed values is illustrated in Figure 12.

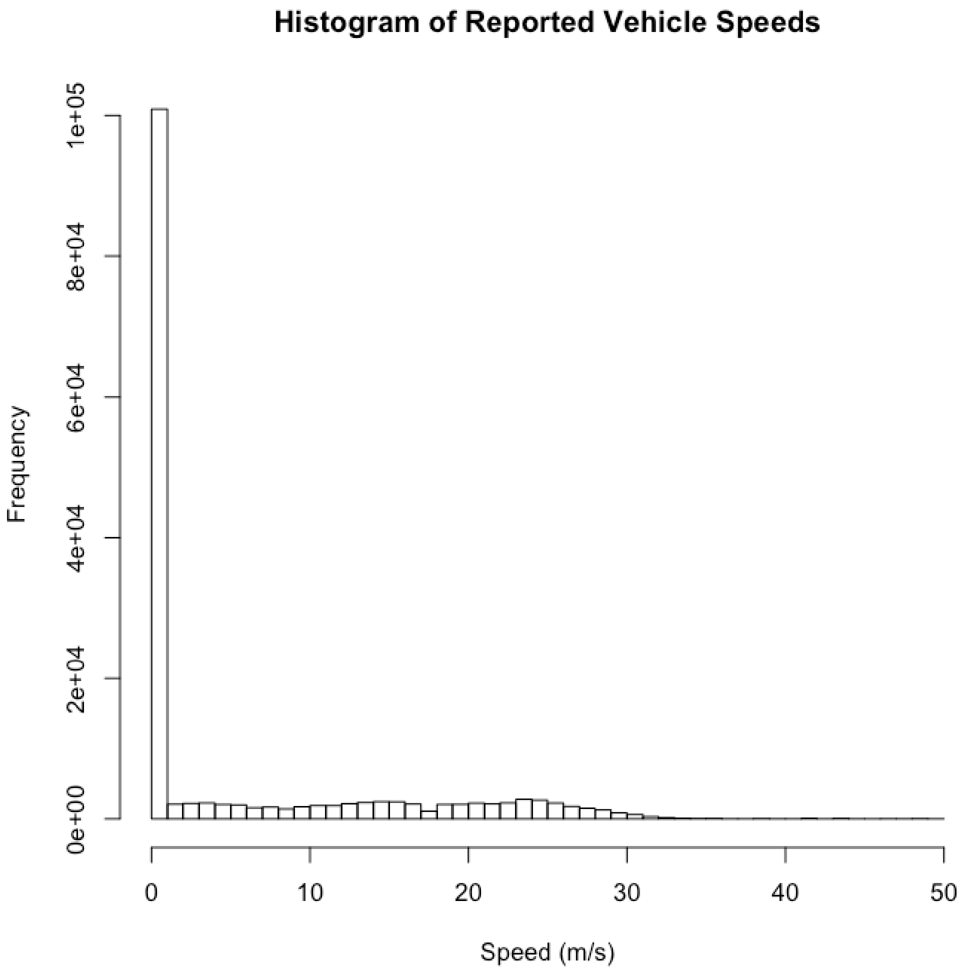


Figure 12. Histogram of reported vehicle speeds – < 50 m/s (Image courtesy of NCAR).

Intake air temperature was reported at 1°C resolution. There were several high outlier temperatures reported, the specific values being 216°, 226°, 229°, 254°, and 255°C. Of the total non-missing observations, 13% were one of these high values. Of the remaining non-missing observations, the overall distribution had several spikes in the number of reports of that specific temperature, as seen in Figure 13. The biggest issue appeared to be the large number of reports of 0°C. Of total non-missing observations, 15% were reported as 0°C. The other spikes occurred at 32°, 33°, 35°, 36°, 44°, 46°, 49°, and 51°C.

The temperature observations were stratified by vehicle ID to determine if particular vehicles were contributing more to the different areas of the temperature distribution. Boxplots of the distributions are found in Figure 14. All vehicles with some distribution (i.e., vehicles with enough unique data points that the spread of data extended beyond the median value) had values above 50°C, but vehicle A1 appeared to be the main contributor of very high temperatures above about 70°C. Many of the vehicles (A0, C11, C12, C2, and C3) reported only values of 0°C, indicating that there were issues with the ability of these vehicles to observe intake air temperature. Figure 14 also shows that some vehicles had no non-missing intake air temperature values.

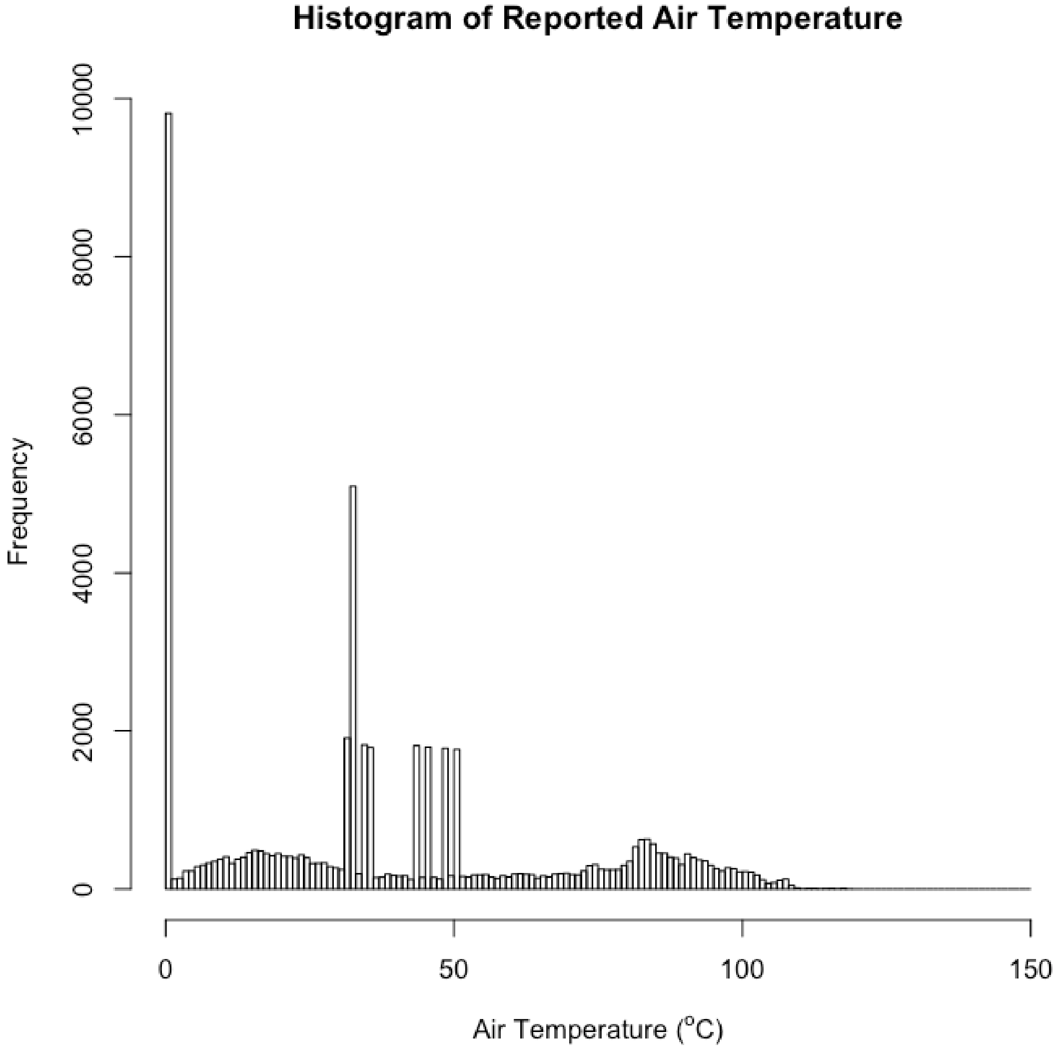


Figure 13. Histogram of observed air temperature – < 200°C (Image courtesy of NCAR).

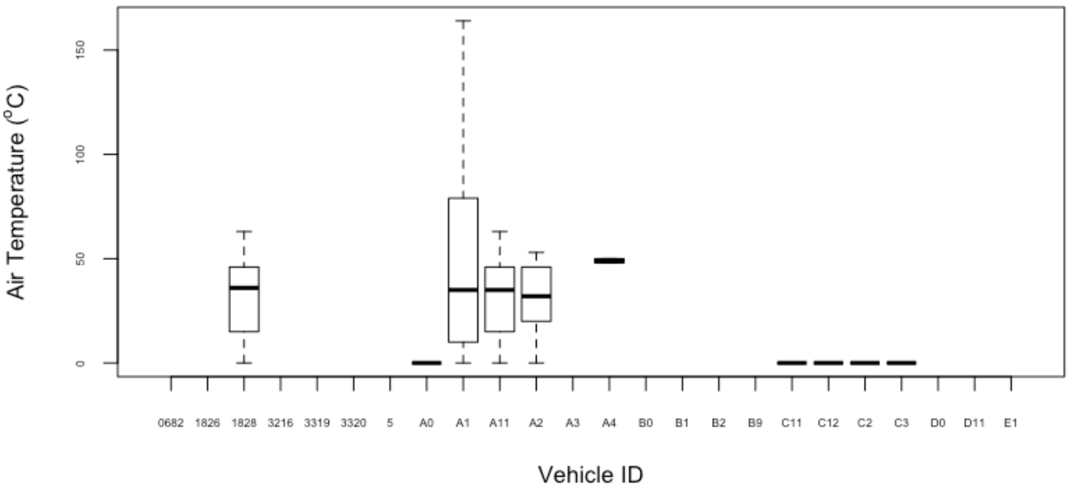


Figure 14. Boxplots of observed air temperature - <200°C (Image courtesy of NCAR).

Barometric Pressure

Barometric pressure was reported at a relatively coarse 10-hPa (hectopascal) resolution. Several of the values were reasonable, although there were several values under 290 hPa and over 1640 hPa up to 213250 hPa that were not. Of the total non-missing pressure observations, 52% were obviously invalid. A histogram of the remaining 48% of non-missing observations is shown in Figure 15.

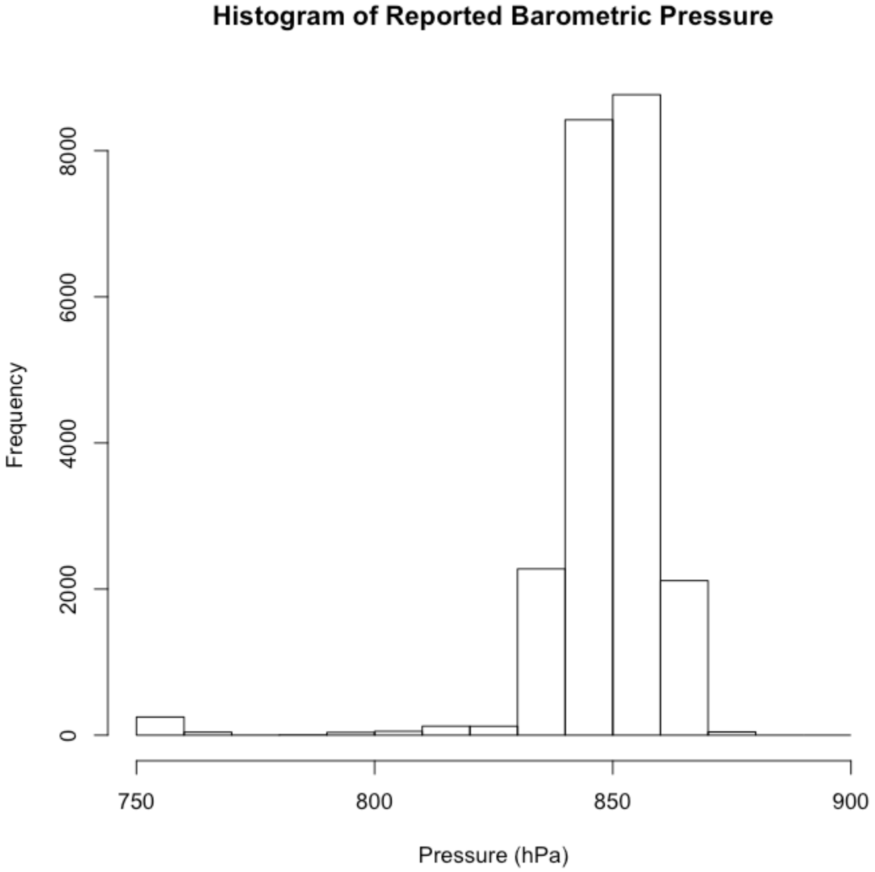


Figure 15. Histogram of observed barometric pressure with obvious errors removed (Image courtesy of NCAR).

Air Temperature – External sensors

Depending on the vehicle, the external air temperature reading came from either the Surface Patrol HD or the RoadWatch sensor that was mounted to the given vehicle. Temperatures were reported at a 1°C resolution by the Surface Patrol HD and 1°F resolution by the RoadWatch. There were several unreasonably high values, specifically at 95°, 124°, 176°, 210°, 211°, 212°, 213°, 214°, 215°, and 255°C, making up 17% of non-missing observations. Otherwise, there was a somewhat reasonable distribution of temperatures from -40°C to about 40°C (Figure 16). It is unlikely that the vehicles experienced the temperatures at the lowest and highest ends of this spectrum.

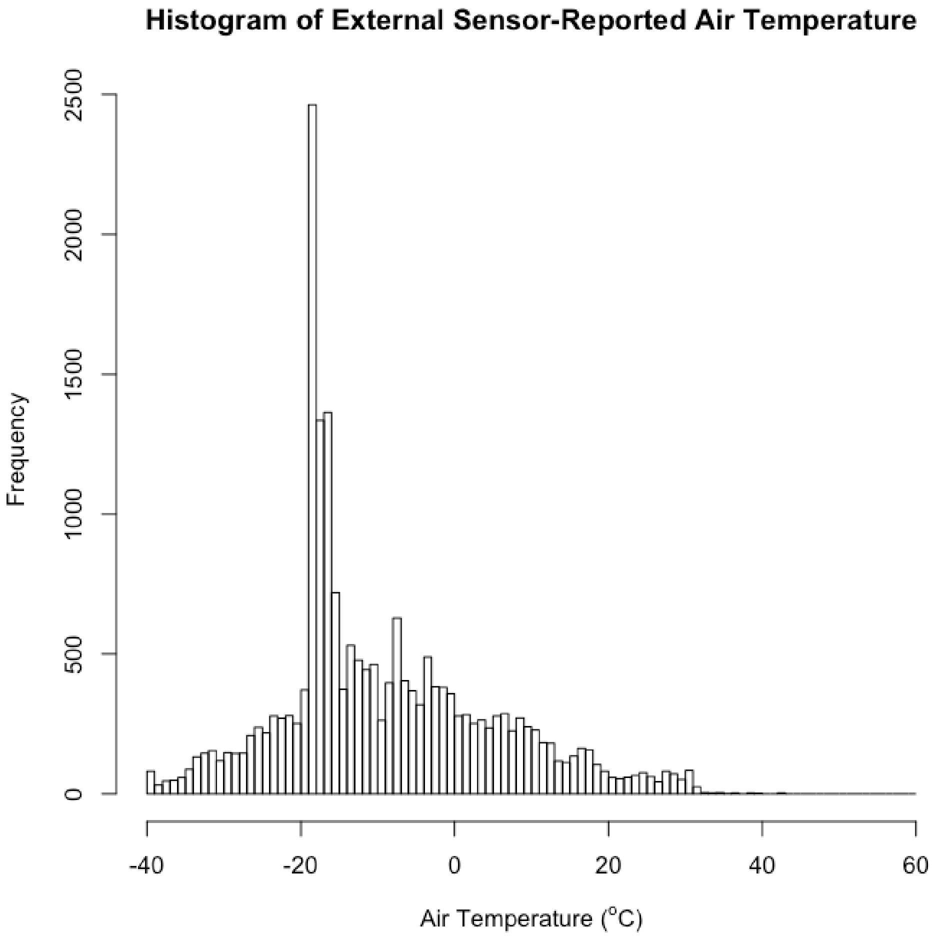


Figure 16. Histogram of external sensor reporter air temperature with invalid data removed (Image courtesy of NCAR).

Surface Temperature - External Sensor

Depending on the vehicle, the surface temperature reading came from either the Surface Patrol HD or the RoadWatch sensor that was mounted to the given vehicle. Temperatures were reported at a 1°C resolution by the Surface Patrol HD and 1°F by the RoadWatch. There were several unreasonably high values, although the only obvious outliers were 111° and 215°C. These made up 1.5% of non-missing observations. Otherwise, the distribution of temperatures was -40°C to almost 90°C (Figure 17). The large spike of -40°C temperatures is likely due to an issue with the sensor. It is interesting to note that the spike of temperature between about -20° and -10°C mirrors that seen in the external sensor-reported air temperature distribution (Figure 16).

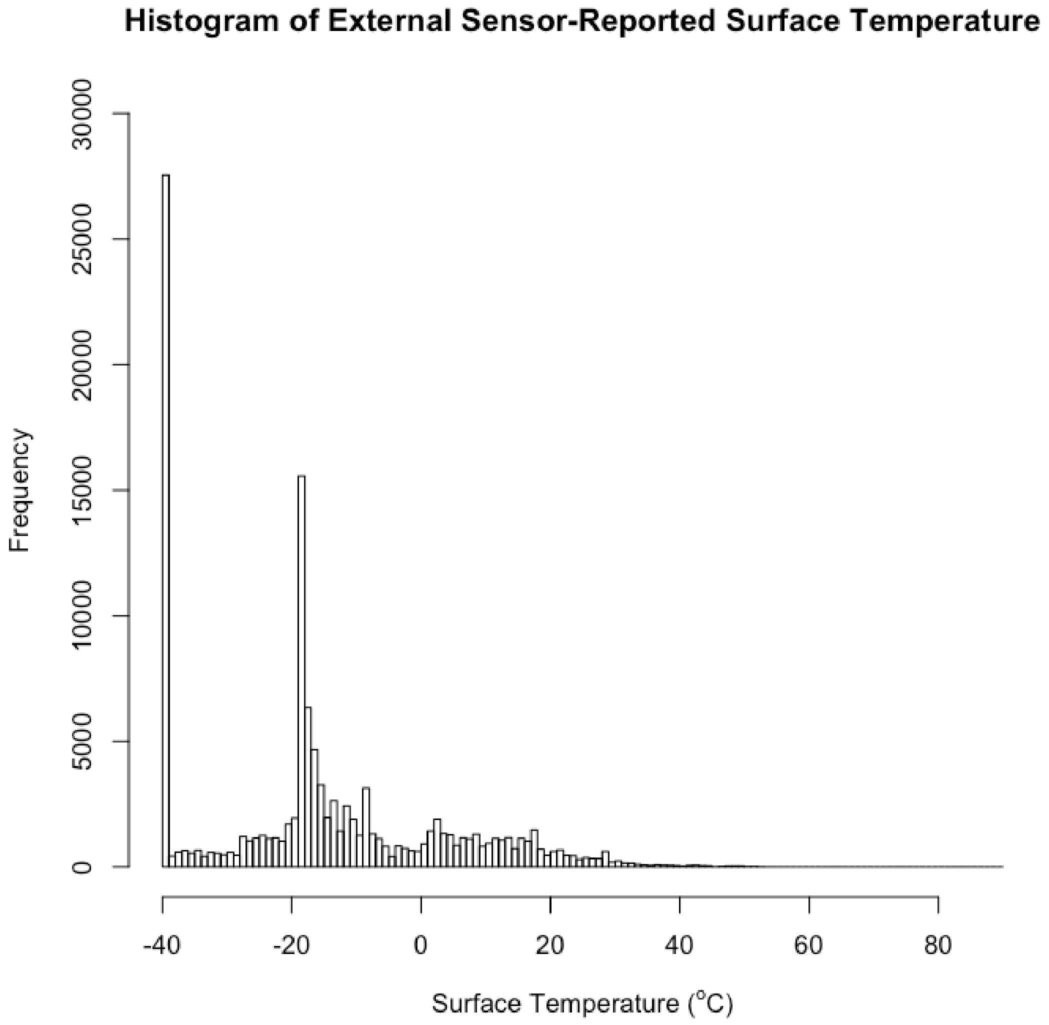


Figure 17. Histogram of external sensor reported surface temperature with invalid data removed (Image courtesy of NCAR).

NCAR

As part of the IMO study, NCAR scientists conducted a field demonstration using a vehicle from the NCAR motor pool. A Ford E350 van was equipped with an OBDII CANbus reader and four external sensors of various makes and models. Five days of testing were conducted during the fall and winter of 2011. A variety of routes were used, focusing on winter weather conditions except for the first test on 16 September. The weather conditions for each case are described in Table 3. The number of observations varied by case day, as the weather conditions and routes for each case led to differing testing lengths. The numbers of (non-missing) observations collected for each case are listed in Table 4. Over 58,000 observations were collected across the five cases. The exact parameters that were collected from each sensor are listed in Table 5.

Table 3. Case dates and weather descriptions for NCAR field study (Table courtesy of NCAR).

Date	Description
16 September 2011	High pressure brought dry weather on this day. Temperatures were warm in eastern Colorado, but significantly cooler in western Nebraska. This was a good case for testing instrument performance in benign weather conditions.
8 October 2011	An upper level trough with associated surface low moved into Colorado to provide the forcing for precipitation. The temperatures were in the 40s along the Front Range at about 5000 ft elevation but much cooler higher up. This resulted in rain at the lower elevations and snow in the mountains. The vehicle encountered the rain/snow transition as it climbed in elevation and descended, along with snow-covered pavement conditions at higher elevations.
19 November 2011	A low pressure system from the west resulted in snowy conditions over the mountains and clear conditions along the front range. Once in the mountains, road conditions ranged from wet to snow covered and slick, particularly on Loveland Pass. Snowfall was heavy at times, greatly reducing visibility.
1 December 2011	A strong trough moved in from the west, resulting in significant snowfall along the Front Range and into the foothills and lower mountains. Road conditions along the canyons and up into the mountains were snow-covered and quite slick.
22 December 2011	There was little large-scale forcing on this day except for slight troughing aloft. A cold front had just moved through the region the previous day, resulting in an upslope snow event that dropped over 6 inches of snow along the Colorado front range during the night. The test was run towards the end of the event, where light snow continued to fall intermittently and the roads were still recovering from the previous night's large accumulation.

Table 4. Number of non-missing observations by test day. Note that for the Surface Patrol HD, there were considerably more surface temperature observations missing than air temperature, so both numbers are given (Table courtesy of NCAR).

Date	CANbus	Airmar	Surface Patrol HD (air / sfc)	RoadWatch	DSC111
16 Sept 2011	17345	17821	17659 / 16469	17809	n/a
8 Oct 2011	9354	9352	9263 / 8839	9352	8792
19 Nov 2011	18505	18505	17630 / 13987	18481	17859
1 Dec 2011	7751	7751	7726 / 2392	7751	7517
22 Dec 2011	4986	4985	4939 / 22	4985	4808

Table 5. List of parameters collected during testing, along with which sensor(s) they were observed with (Table courtesy of NCAR).

	Vehicle CANbus	Airmar	Surface Patrol HD	Road Watch	DSC 111
Air Temperature	✓	✓	✓	✓	
Barometric Pressure	✓	✓	✓	✓	
Relative Humidity/ Dewpoint		✓	✓		
Wind Direction		✓			
Wind Speed		✓			

	Vehicle CANbus	Airmar	Surface Patrol HD	Road Watch	DSC 111
Surface Temperature			✓	✓	
Grip					✓
Surface State (e.g., snow)					✓
Acceleration	✓				
Yaw	✓				
Roll	✓				
Speed	✓				
Steering Angle	✓				
Brake Status	✓				
Traction Assistance	✓				
Latitude	✓				
Longitude	✓				
Time	✓				

In addition to the observations noted in Table 5, a high-definition video camera was mounted to the vehicle's windshield to serve as a source of verification for different segments of the route. The cases with the camera available were 8 October, 19 November, and 1 December. The video was viewed after the data collection and the precipitation, pavement condition, and visibility noted, as done in driver reports from the 2009 and 2010 Development Test Environment Experiments (DTE09/DTE10). Also, because wiper status was not collected from the CANbus, the wiper status was noted along with the speed limit of each section of road.

Chapter 3 Analysis Methods

Statistics

The various sensors on the vehicle/vehicles were compared using three statistics: the Mean Difference (MD), Mean Absolute Difference (MAD), and correlation. The MD determines the bias between different instruments and the baseline chosen. For example, an MD of -1°C when comparing the surface temperatures of the Surface Patrol HD and the RoadWatch, with the RoadWatch as the baseline, would indicate that the Surface Patrol HD tends to observe cooler than the RoadWatch. The MAD is similar to the MD, but takes a mean of the absolute difference, resulting in a positive value. It indicates how far away, on average, an instrument's observations tend to be from the baseline. The correlation indicates how closely the instrument's observations match the temporal trends of the baseline. These statistics are designed such that no "truth" value is assumed among the observations being compared. Three similar methods, the bias, Mean Absolute Error (MAE), and correlation are used to compare the instruments with the nearest Road Weather Information System (RWIS) station, however in the case of these statistics the RWIS station observations are assumed to be truth.

When comparing amongst the vehicle sensors, all observations were time-matched, which allowed an accurate comparison across all cases and time periods. Comparison of the vehicle observations with nearby RWIS stations presented a greater challenge due to the complex terrain much of the demonstration was run over. To account for the elevation variability of the terrain, matching to nearby RWIS stations was restricted depending on observation locations.

Minnesota Data Analysis

External Sensors

Observations of air and pavement temperature from external sensors, including the RoadWatch and Surface Patrol HD sensors, were analyzed for accuracy and bias from 1 November 2011 – 31 May 2012. Close by RWIS stations, spatially and temporally, were used as "truth" data and were compared directly to these observations. Statistics such as MAE and bias were used and plots (including histograms and scatterplots) were also utilized in the analysis. Preprocessing of these data was performed by filtering for matches between the mobile observation and the RWIS station observation that occurred within 15 minutes and 25 km of one another. This left an initial 65,340 matches out of a possible 114,807. For air temperature, 16,258 additional matches were removed due to missing RWIS station or external sensor data, which left 48,324 matches for the final air temperature analysis. For surface temperature, 43,567 matches had to be removed due to missing observations from either the RWIS station or external sensor, which left 21,773 matches for the final pavement temperature analysis.

CANbus Parameters

Identical to the analysis that was discussed in the previous subsection, these data were pre-processed by filtering over space and time. MAE and bias as well as scatterplots and histograms were generated to assess the accuracy of the CANbus observations when compared to the RWIS station observations.

Segment vs. Point Analysis

All available observations were compiled with their corresponding segment mean. In cases where point observations were not on a segment (for example, if they were at the shed), the observations were not used. For every five-minute window, this analysis compared each point to its corresponding mean value. Analysis included the MD (point observation – segment mean), MAD (abs(point observation) – abs(segment mean)), correlation coefficient, and histogram of differences. Data analyzed included CANbus air temperature and pressure, and external air temperature and surface temperature.

Latency

Analysis varied by state due to the way data were recorded. In Minnesota, all data were transmitted close to real-time. Thus, analysis simply focused on comparing the percentage of observations that arrived beyond their designated five-minute window. For instance, at 10:55:00, all observations from 10:50:00 to 10:54:59 are assessed. Observations with timestamps from 10:50:00 to 10:54:59 that arrived after 10:55:00 are considered latent.

Value to Forecast

Road weather forecasts, specifically of pavement temperature, were generated over the state of Minnesota at all RWIS site locations and for 1-km VDT road segments at variable distances around each site. An analysis of the RWIS pavement temperature observation, the initialized forecast, and the VDT pavement temperature output was performed to initially understand the accuracy (i.e., MAE) of the VDT output (which is essentially the average pavement temperature from the mobile observations) when compared with the RWIS station observation. Additionally, an analysis of the VDT segment statistics and the initialized forecast away from the RWIS site was performed to determine how variable the two were when compared to one another. The assumption for this is that if the VDT segment analysis close to the RWIS site was determined to be reasonably accurate, that higher variability between the forecast and VDT analysis away from the RWIS station would prove that the mobile observations were adding/detracting value to/from the forecast.

Nevada Data Analysis

External Sensors

The period used for comparison is from a trip where a vehicle was driven from Reno, NV to the Morro Bay, CA area. The route is shown in Figure 18. A Surface Patrol HD, a RoadWatch, and an Airmar sensor were all attached to the vehicle, and values from these sensors were compared with one another as well as to nearby RWIS stations. The comparison with the nearby RWIS station was made only if the station observation was taken within 15 minutes and 25 km of the vehicle. These criteria were employed to help control for the complex terrain that exists along portions of the route.

Some of the instrument observations were removed from the analysis for appearing to be anomalous or erroneous without any formal quality checking. Some latitude/longitude pairs were reported as 90°N, 180°W and were therefore marked as missing. These accounted for less than 0.1% of latitude/longitude pairs. There were 20 missing observations from the RoadWatch (0.03% of total). The values 127°C for air temperature, 127% for relative humidity, and 255°C for surface temperature were consistently reported by the Surface Patrol HD, and these values were marked as missing (22%, 2%, and 2% of the total, respectively). Values of 127 were also reported by the Airmar (64 observations of each variable measured, or 0.1% of the total) and marked as missing.

Figure 18. Map of vehicle route, shown by bold black line (Image courtesy of NCAR).

The observations were recorded over three time periods (02 - 03 March 2012, 6 March 2012, and 7-8 March 2012. The number of observations collected for each period is given in Figure 19. Each of these three time periods was analyzed separately.

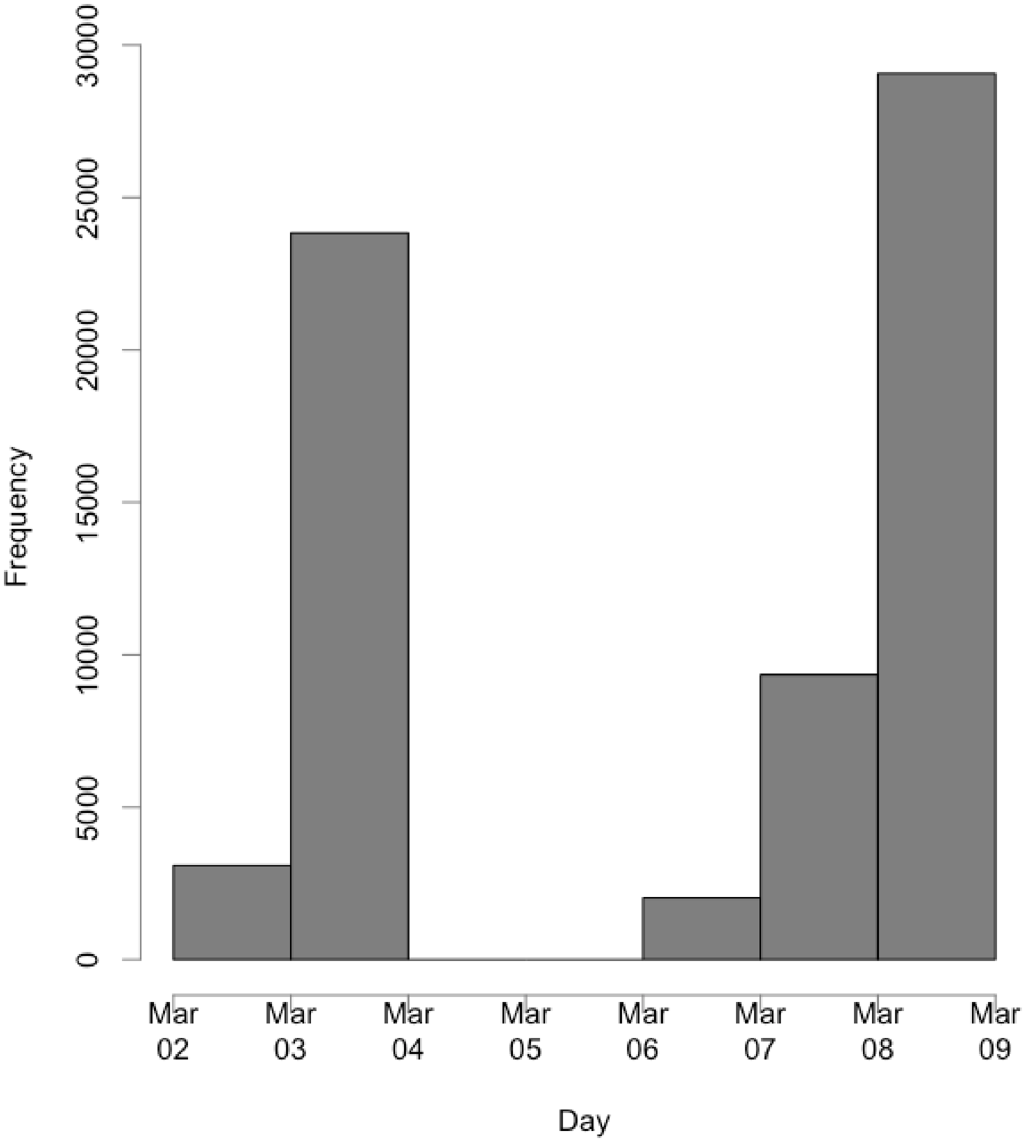


Figure 19. Number of observations collected on each day (UTC) (Image courtesy of NCAR).

CANbus Parameters

Data from the NDOT heavy-duty vehicles were received and analyzed over the period from 1 November 2011 to 31 May 2012. Data were received from 15 different vehicles (Peterbilt heavy duty trucks). Of the 22,054 total heavy duty observations, 4,509 had no vehicle identification associated with them (20%).

The observations were run through the VDT and the output, specifically the intake air temperature and barometric pressure, were compared with the nearest RWIS station to determine the quality of the vehicle data. An RWIS match was made only if the station was within 50 km and 30 minutes of the vehicle observation. Of the total vehicle observations, 81% were reported as missing. For the remaining data, the non-QCed data were compared with the nearest RWIS station with four exceptions. These were removal of values of 216°C and 255°C from the air temperature, 0 hPa from the barometric pressure, and one pressure observation of 2550 hPa. This accounted for another 1.0% and 12% of observations respectively.

Segment vs. Point Analysis

All available observations were compiled with their corresponding segment mean. In cases where point observations were not on a segment (for example, if they were at the shed), the observations were not used. For every five-minute window, this analysis compared each point to its corresponding mean value. Analysis included the MD (point observation – segment mean), MAD (abs(point observation) – abs(segment mean)), correlation coefficient, and histogram of differences. Data analyzed included CANbus air temperature and pressure, and external air temperature and surface temperature.

Latency

Analysis varied by state owing to the way data were recorded. Analysis focused on comparing the percentage of observations that arrived beyond their designated five-minute window. For instance, at 10:55:00, all observations from 10:50:00 to 10:54:59 are assessed. Observations with timestamps from 10:50:00 to 10:54:59 that arrived after 10:55:00 are considered latent. For Nevada, only "snapshots" were sent every five minutes, with archived data to follow. Unfortunately, there was no way to discern a late observation from an archived observation. Nevada is currently performing post-hoc analyses to attempt to solve this. In the meantime, we used a crude method. Because archived data are uploaded at the end of the day, we computed the number of observations that were more than five minutes late, but less than one hour late. Some of these may be truly latent observations, while some may be archived data.

NCAR Data Analysis

Statistical comparisons between the vehicle observations and the nearest RWIS station were made for the three cases with camera verification available (8 October, 19 November, and 1 December). Although the RWIS stations typically measure barometric pressure, there were no non-missing barometric pressure observations available for the times and locations examined here and thus barometric pressure was not analyzed.

With only one vehicle present during testing, it is impossible to use the data to modify the VDT road weather analysis algorithms. However, with the camera verification available for cases 8 October, 19 November, and 1 December, it was possible to test the VDT 3.0 algorithms against this verification to an extent, as well as the general data collected from the vehicle, to form guidelines to move forward with continued testing and development. The results of this testing will be used in conjunction with other datasets for future algorithm modification.

To simulate the one-mile segments used in the VDT, a median or mode (depending on whether the observation was continuous or discrete) was taken every minute for each of the input observations from the vehicle for use in testing the algorithms. Ancillary data, dewpoint temperature, radar reflectivity, cloud mask, visibility, and wind speed, were matched up using the nearest surface station, gridded radar reflectivity, and satellite data. Wiper status and speed ratio (specifically speed limit) were determined from the video. Headlight status was set to “low” for every observation, based on information from the driver, and ABS and stability control, which were not reported, were set to “not engaged” for every observation. The algorithm output was then compared with the verification determined by the video. The modal observation occurring in the one-minute time span was chosen as the verification.

Chapter 4 Results

Minnesota

External Sensors

The external sensor data were compared to nearby RWIS stations for air and pavement temperature observations. Figure 20 illustrates the distribution of the error (bias) statistics for air temperature (18a) and pavement temperature (18b). Overall, the bulk of the comparisons appeared to cluster between -10°C and +10°C with the mode of the histogram right around 0°C for air temperature. The bulk of the pavement temperature errors resided between -25°C and +25°C with the mode being slightly less than 0°C, which indicates the possibility of a slight cold bias. Figure 21 is a scatterplot of the same datasets and shows the possibility of a slight warm by bias for air temperature but no obvious bias for pavement temperature.

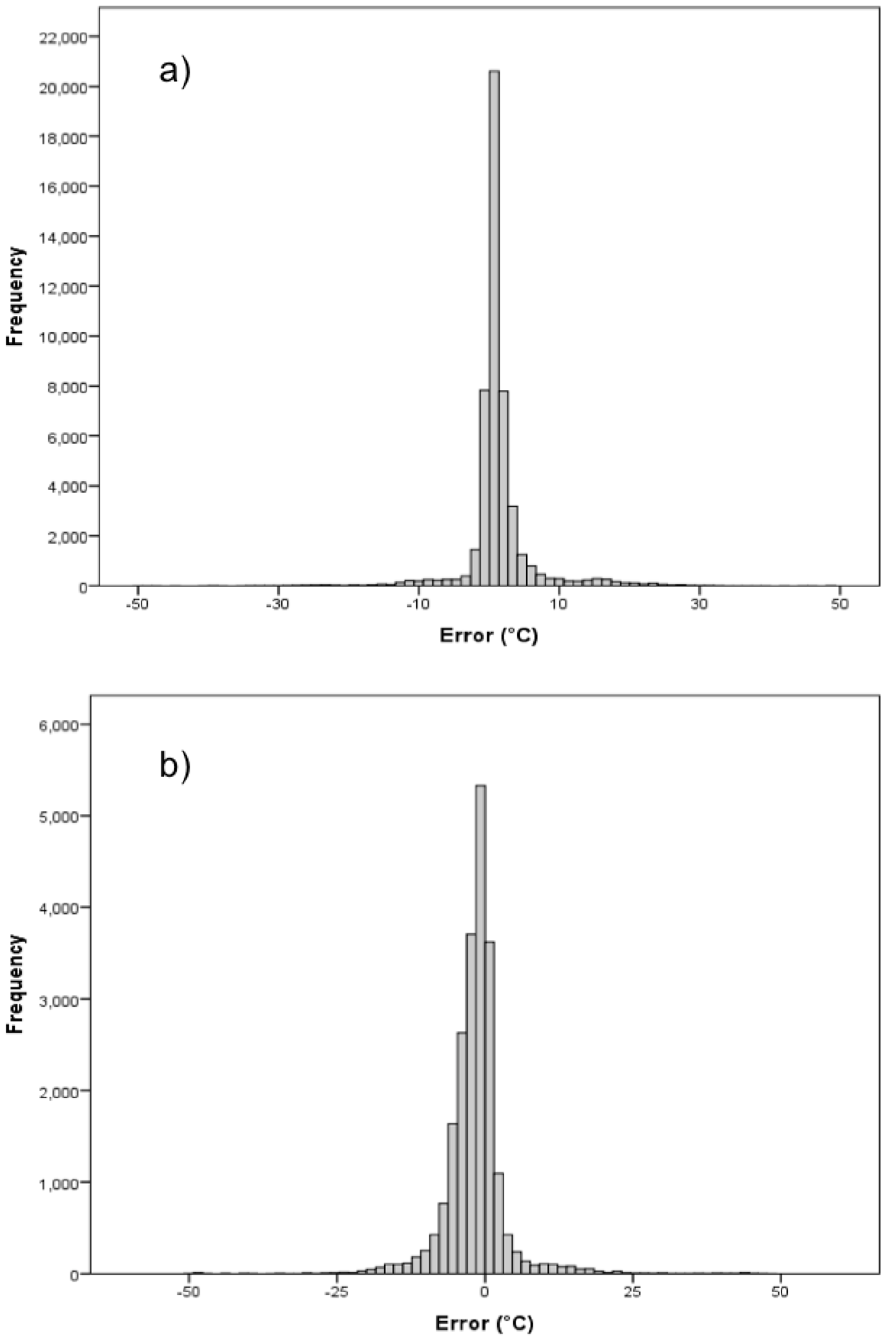


Figure 20. Histogram of error (bias) statistics for external air temperature (a) and external pavement temperature (b) (Image courtesy of NCAR).

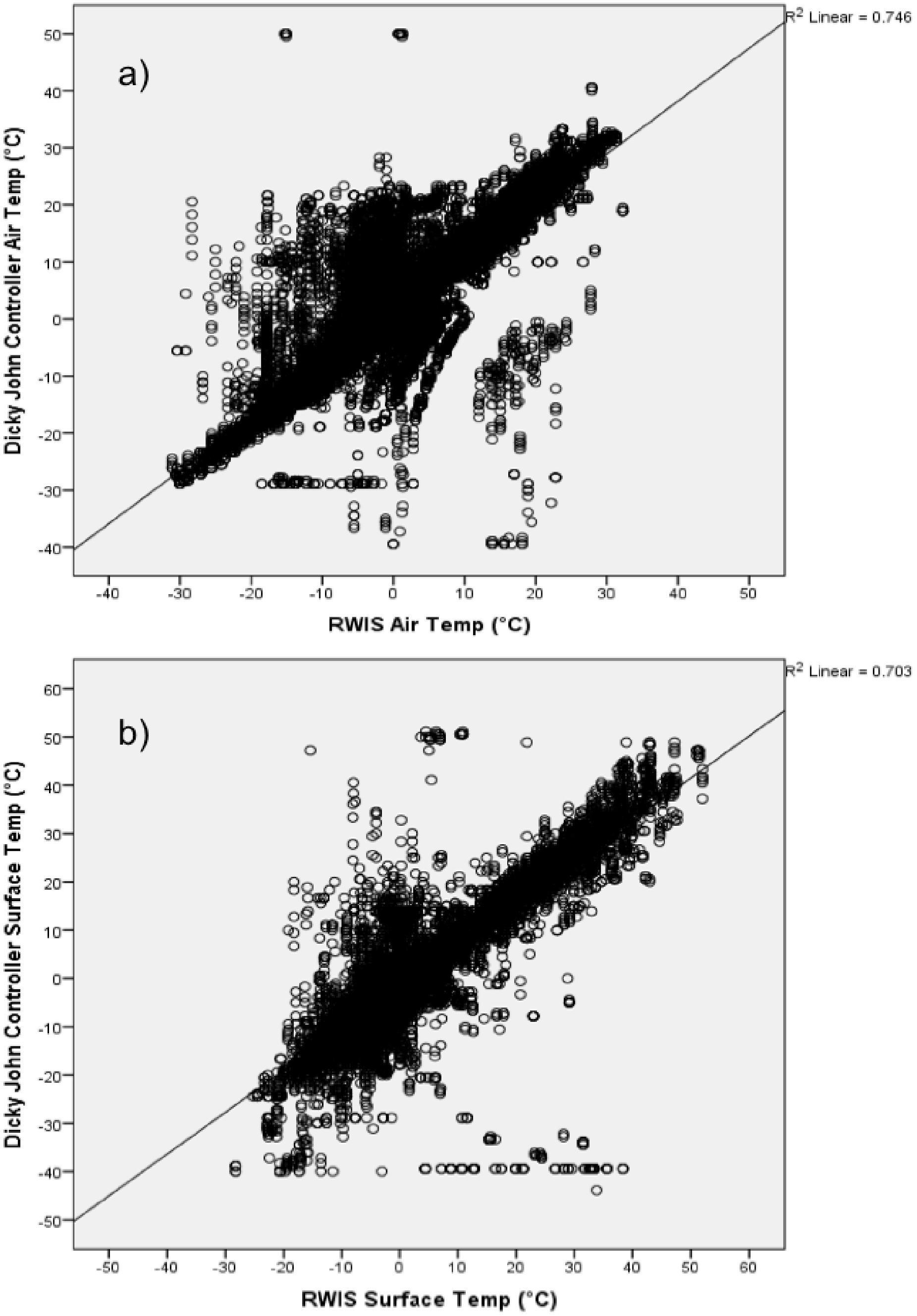


Figure 21. Scatterplot of RWIS air temperature vs. external air temperature (a) and RWIS pavement temperature vs. external pavement temperature (b) (Image courtesy of NCAR).

Table 6 lists the bulk statistics over the entire time period with no stratification for bias and MAE. These results show a slight warm bias (+1.23°C) for air temperature and a slight cold bias (-1.86°C) for surface temperature. MAE values of 2.63°C for air temperature and 3.66°C are reasonably low. However, the MAE values are relatively higher than the bias statistics, indicating that the warm bias for air temperature and cold bias for pavement temperature are not consistent and likely cannot be corrected for. Overall, the errors are low enough that the results likely lie within the noise of the resolution and precision of the instruments.

Table 6. Statistical comparison of Dicky John controller air temperature and surface temperature with nearest RWIS station (Table courtesy of NCAR).

	# Obs	Bias	MAE	Correlation
Air Temperature	48324	1.23	2.63	0.86
Surface Temperature	21773	-1.86	3.66	0.84

Table 7 lists the statistics stratified by distance away from the RWIS station. Surprisingly, the results for both air temperature and pavement temperature appear slightly better the further away from the RWIS station. Again, these results still likely fall within the noise of the variability of the sensors.

Table 7. Statistical comparison of Dicky John controller air temperature and surface temperature with nearest RWIS station, stratified by distance in kilometers (Table courtesy of NCAR).

	Air Temperature			Surface Temperature		
	# Obs	Bias	MAE	# Obs	Bias	MAE
0-4.99 km	17475	1.58	2.94	6787	-2.48	4.44
5-9.99 km	10258	1.09	2.47	4264	-2.26	3.15
10-14.99 km	8463	0.36	2.39	4507	-1.22	3.04
15-19.99 km	5201	1.47	2.67	2911	-1.08	3.40
20-24.99 km	3513	1.09	2.23	1931	-1.21	3.37
25-29.99 km	2203	2.24	2.63	1097	-2.52	4.97
30-34.99 km	784	1.46	1.81	115	-0.87	2.16
35-39.99 km	270	-0.07	2.22	127	-0.67	2.27
40-44.99 km	126	-0.43	3.28	34	-1.20	1.82
45-50 km	31	-0.21	0.82	--	--	--

Table 8 lists the results stratified by time away from the RWIS station observation. While the results for the pavement temperature appear worse over time, the results for air temperature are slightly better.

Table 8. Statistical comparison of Dicky John controller air temperature and surface temperature with nearest RWIS station, stratified by time difference in seconds (Table courtesy of NCAR).

	Air Temperature			Surface Temperature		
	# Obs	Bias	MAE	# Obs	Bias	MAE
0-299 sec	36481	1.10	2.63	17911	-1.75	3.64
300-599 sec	8037	1.62	2.65	3320	-2.25	3.69
600-899 sec	1139	2.46	3.14	221	-2.76	4.10
900-1199 sec	1914	1.42	2.04	136	-1.94	4.34
1200-1499 sec	567	0.97	2.63	116	-3.59	5.41
1500-1800 sec	186	0.35	3.78	69	-3.05	3.75

Table 9 lists the results by month of the year. The air temperature errors are very consistent and low over the winter months. The errors for the pavement temperature are also consistent over the cold winter months but spike during the months of April and May. This is likely due to the difference in the mechanics of the observations. The RWIS stations use embedded pucks to measure the pavement temperature and the mobile sensors measure the pavement temperature with an infrared sensor.

Thus, the two temperature measurements are slightly different. The embedded pucks measure from a bulk depth, while the infrared sensor is a skin temperature only.

Table 9. Statistical comparison of Dicky John controller air temperature and surface temperature with nearest RWIS station, stratified by month (Table courtesy of NCAR).

	Air Temperature			Surface Temperature		
	# Obs	Bias	MAE	# Obs	Bias	MAE
November	1310	2.63	4.22	273	-2.11	5.26
December	1589	1.27	3.29	790	-1.09	3.67
January	15481	1.17	2.55	7303	-1.25	2.96
February	18246	1.32	2.37	9084	-1.32	3.24
March	4301	1.29	2.88	1724	-1.56	4.16
April	3362	1.04	2.71	1087	-7.27	8.03
May	4035	0.62	2.98	1512	-4.77	5.60

CANbus

Initially, simple data filtering was accomplished by eliminating obviously erroneous values for air temperature and barometric pressure. Additionally, values that had no valid location associated with it were also filtered out. After filtering out erroneous CANbus air temperature values (0 K, 2047.97 K) and values with no associated latitude or longitude, 10,004 air temperature observations remained. After filtering out erroneous CANbus barometric pressure values (0 mb) and values with no associated latitude or longitude, 31,570 barometric pressure observations remained. When examining the remaining data set, the two most common locations (latitude=44.24, longitude=-95.63 and latitude=45.15, longitude=-95.01) had no RWIS that was reporting nearby. Filtering out these locations meant that 81.4% of the CANbus air temperature values were removed and 83.0% of the CANbus barometric pressure values were removed.

Where possible, the remaining values were matched with the nearest RWIS observations (within 50 km). Finally missing RWIS values were removed. The following table (Table 10) lists the accuracy statistics for this data set:

Table 10. Accuracy statistics for Minnesota CANbus data set (Table courtesy of NCAR).

	# Obs	Bias	MAE	Correlation
Air Temperature	43	-0.47 °C	7.01 °C	0.57
Barometric Pressure	140	4.69 mb	35.53 mb	0.51

Point vs. Segment

Air temperature

There is a statistically significant, but not especially strong, relationship between point and segment-based mean CANbus air temperatures (Figure 22). The correlation coefficient is 0.50, with a mean difference of -0.24°C. The mean absolute deviation is 6.05°C, relatively large, and based on some large differences between air temperature data in a given segment (e.g., Figure 23). The difference between the point and segment mean air temperature is 0°C in 33% of the cases; 36% of the cases have a point observation below the segment mean, and 31% have a point observation higher than the segment mean.

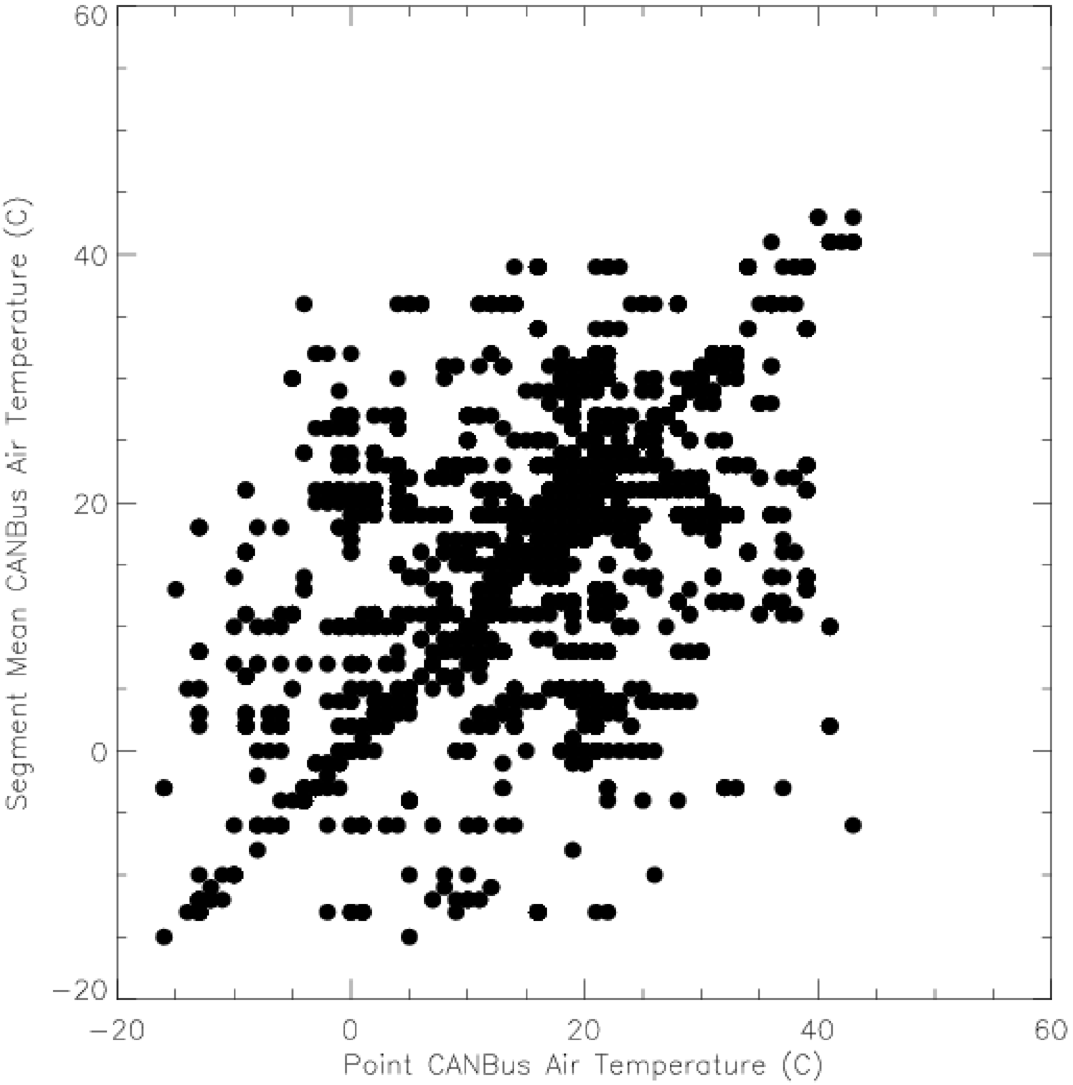


Figure 22. Minnesota CANbus air temperature, point vs. segment mean (Image courtesy of NCAR).

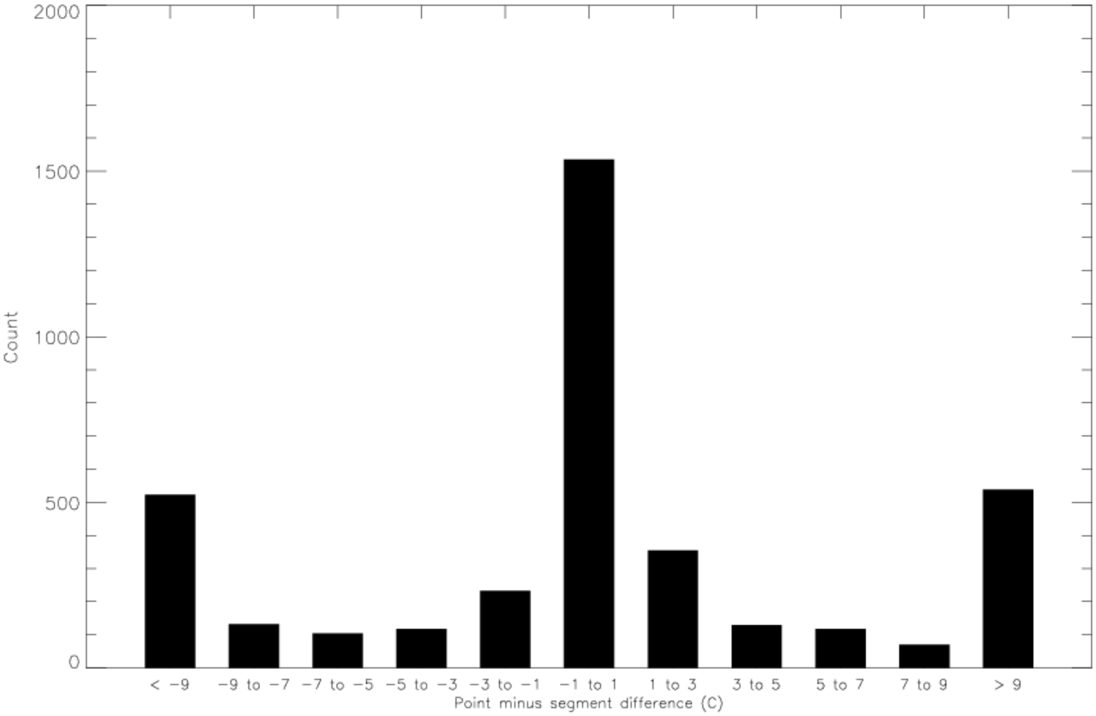


Figure 23. Minnesota CANbus air temperature differences, point vs. segment mean (Image courtesy of NCAR).

Barometric pressure

Barometric pressure CANbus observations historically have lacked precision and accuracy (e.g., Chapman et al. 2010, Anderson et al. 2012). The lack of precision is noticeable here as well; however, the correlation between the point and segment-based mean is 0.69 (Figure 24). However, the mean difference (-0.35 hPa) and the mean absolute difference (5.73hPa) are very reasonable, indicating close correspondence between the point and segment-based data. In the vast majority of cases (54%), the point and segment data are the same (Figure 25). In 24% of the cases, the point measurement is below the segment-based mean, and in the remaining 22% of cases, the point measurement is higher than the segment-based mean.

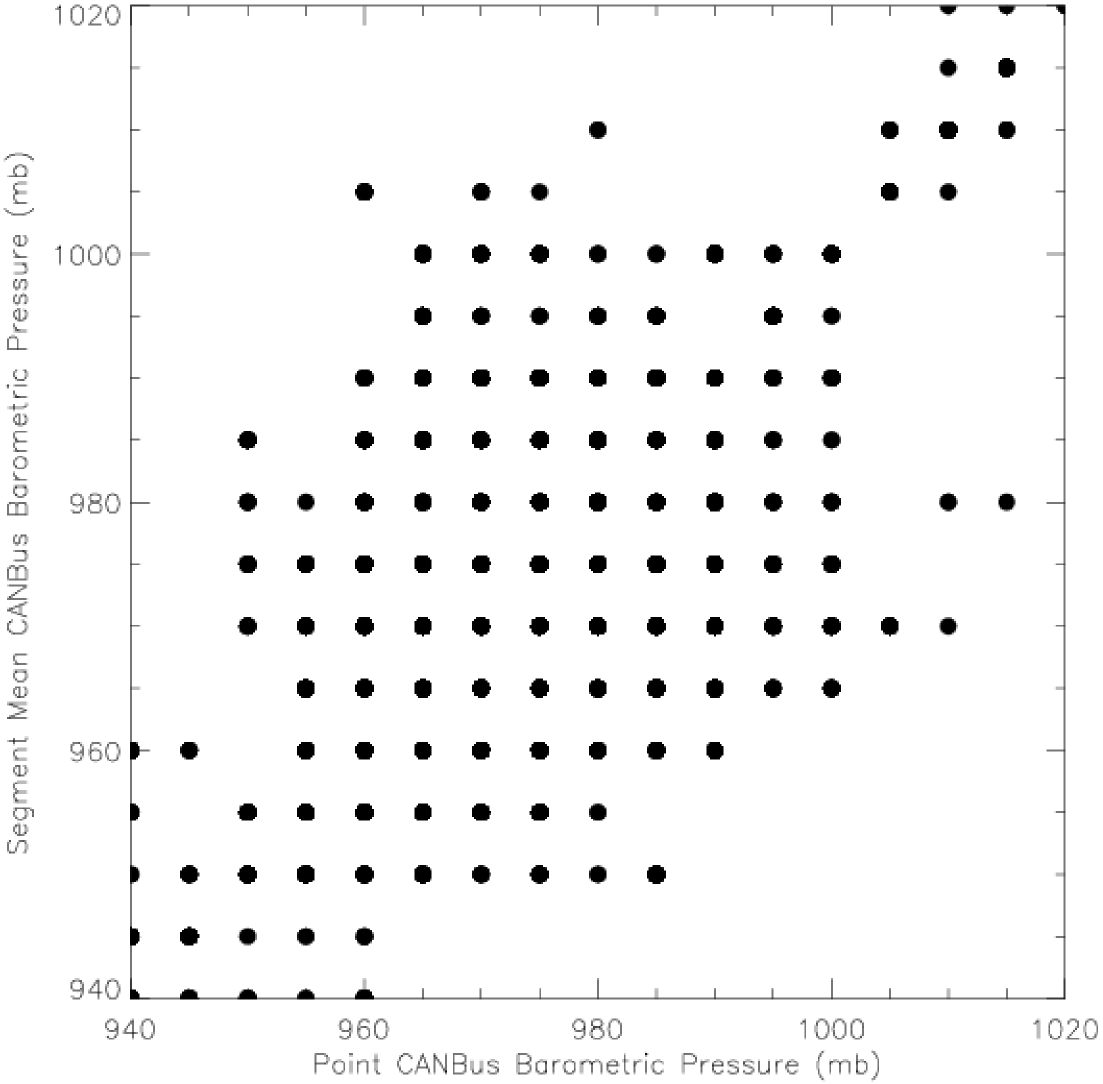


Figure 24. Minnesota CANbus barometric pressure, point vs. segment mean (Image courtesy of NCAR).

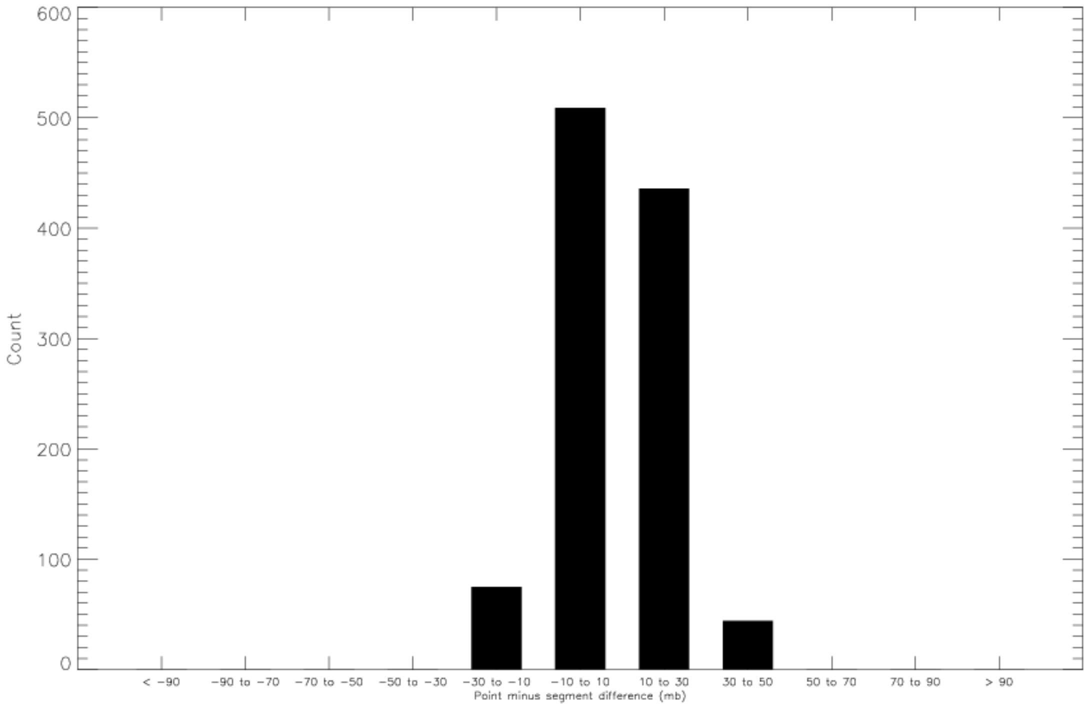


Figure 25. Minnesota CANbus barometric pressure differences, point vs. segment mean (Image courtesy of NCAR).

External data

Air temperature

Compared to Minnesota CANbus air temperatures, the external air temperature data show lower correspondence between point and segment-based mean observations (Figure 26). The correlation coefficient is 0.36, quite poor, with a mean difference of -0.10°C and a mean absolute difference of 7.35°C. There appears to be numerous cases where the segment scatter is incredibly and unrealistically high. Additional QC will be needed to handle these noisy data. In 20% of the cases, the point and segment data are identical (Figure 27), with the point observation being higher (lower) than the segment-based observation 41% (39%) of the time.

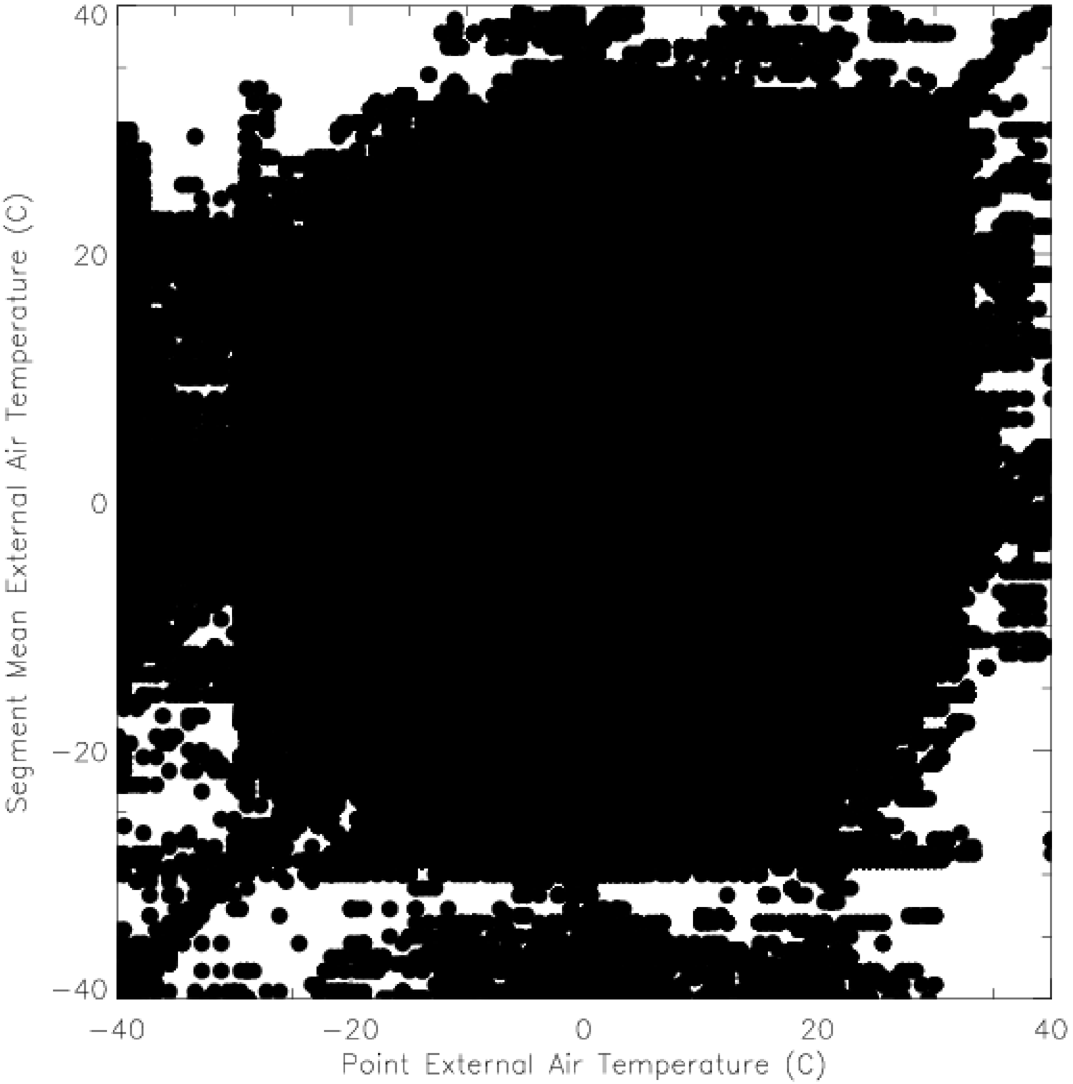


Figure 26. Minnesota external air temperature, point vs. segment mean (Image courtesy of NCAR).

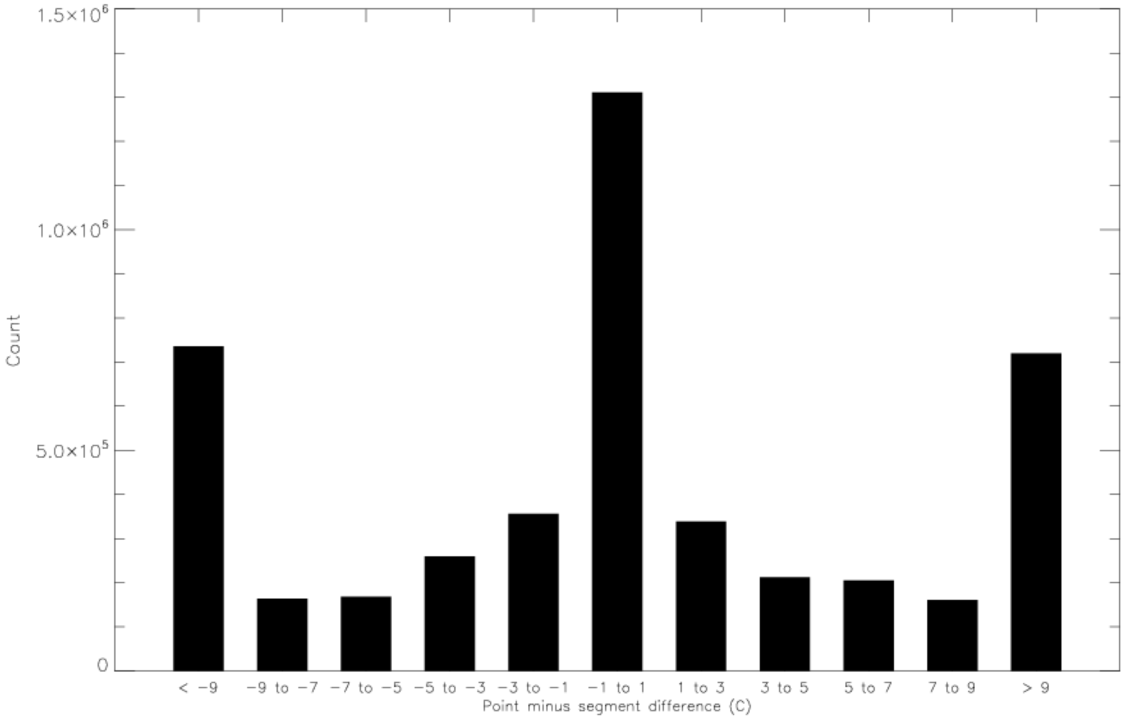


Figure 27. Minnesota external air temperature differences, point vs. segment mean (Image courtesy of NCAR).

Surface temperature

The external surface temperature data show broad similarity to the external air temperature findings above (Figure 28). The correlation between the point and segment-based mean is 0.38, with a mean difference of -0.15°C and a mean absolute difference of 8.70°C. In only 15% of the cases are the point and segment data the same (Figure 29). For 44% of the time, the point observation is higher than its corresponding mean, and 41% of the time, the point observation is lower than the segment-based mean.

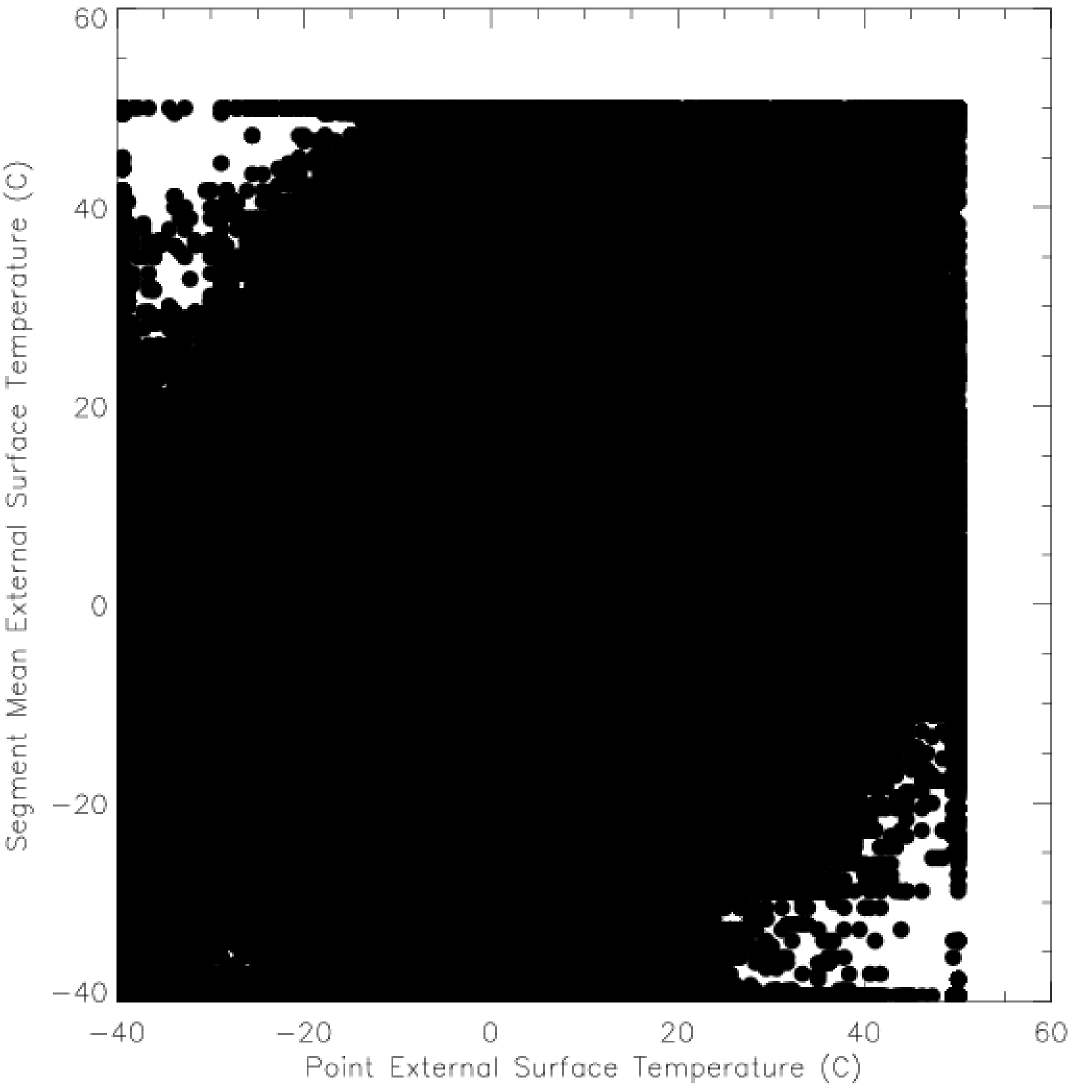


Figure 28. Minnesota external surface temperature, point vs. segment mean (Image courtesy of NCAR).

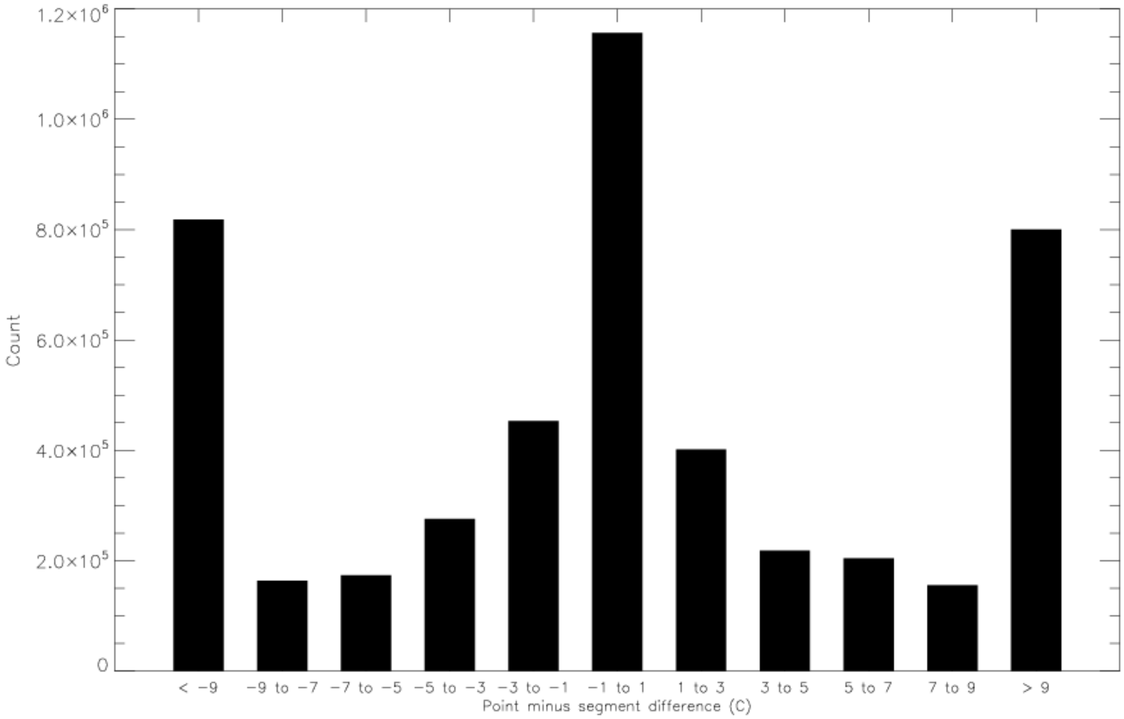


Figure 29. Minnesota external surface temperature, point vs. segment mean (Image courtesy of NCAR).

Latency

Latency analysis for Minnesota is more straight-forward than Nevada given the way that data were received at NCAR. A time-series plot of the percentage of latent observations per day (Figure 30) shows similar variability to Nevada. There is no consistent pattern in the data, with latency ranging from 0% on some days to 100% on other days. It is not apparent as to why this disparity occurred. In terms of raw latent numbers, most days had less than 10,000 latent observations (Figure 31). There is a noticeable drop in the number of latent observations later in the experiment.

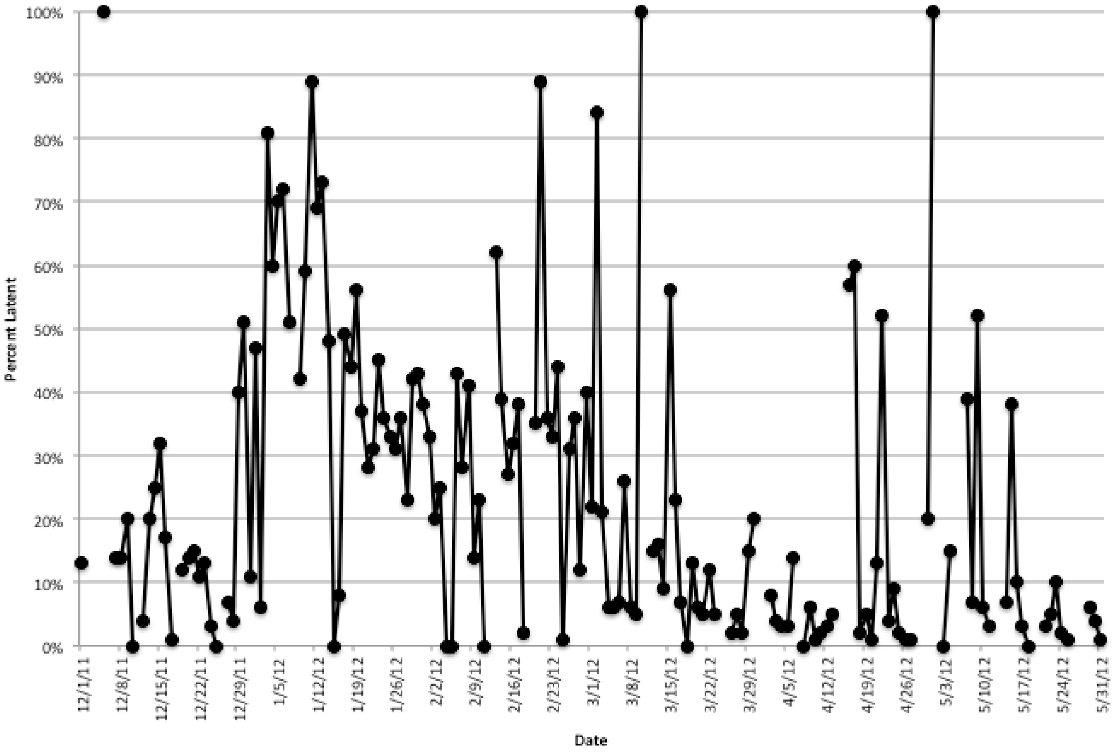


Figure 30. Percent of latent observations for Minnesota (Image courtesy of NCAR).

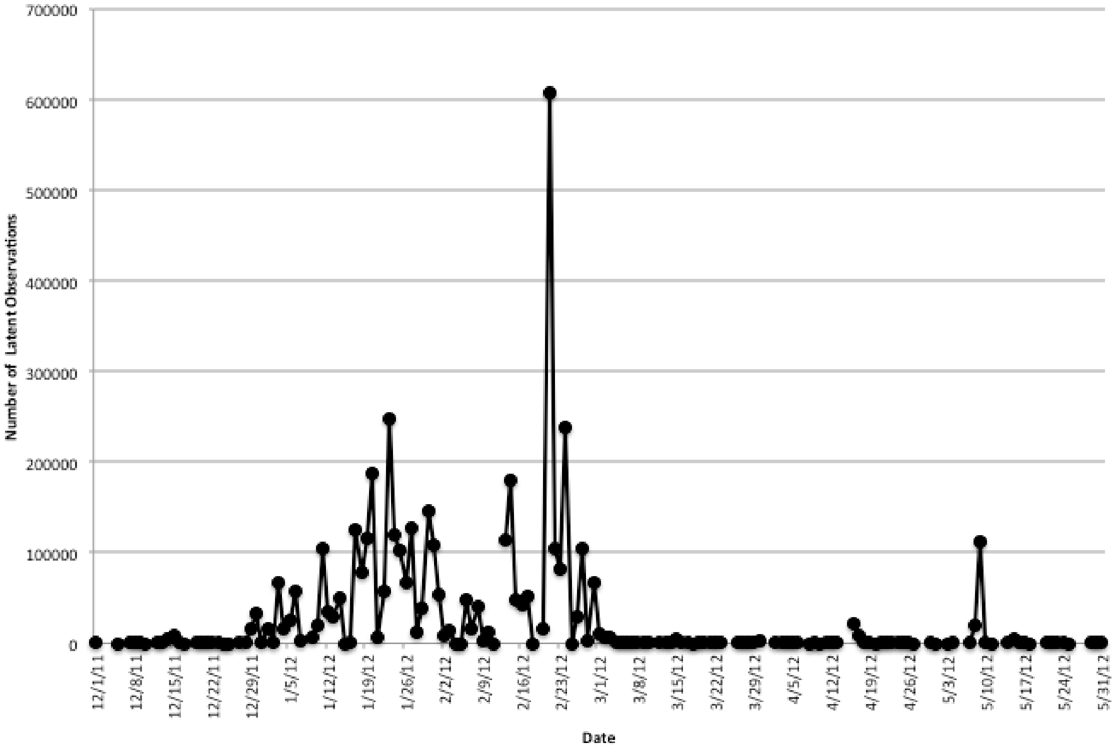


Figure 31. Count of latent observations for Minnesota (Image courtesy of NCAR).

Value to Forecast

VDT surface temperature analysis data were analyzed together with RWIS surface temperature observations and forecasted temperatures over a period from 23 December 2011 to 26 April 2012. Of the 671 total data points, 48.0% were reported as missing. To remove any outliers, values of the VDT analysis that were less than -35°C were eliminated. This accounted for an additional 0.9% of the observations.

First, the non-missing VDT analysis data and the forecasted surface temperatures were compared to the RWIS observations within 2 km of the station. The comparison of these data is given in Table 11. The comparison shows that the VDT analysis data are reasonably consistent with the RWIS observations and that the forecasted surface temperatures are nearly representative of the conditions observed at the RWIS stations. The scatterplot in Figure 32 shows the strong correspondence between the VDT analysis and the RWIS surface temperatures at this distance and the plot in Figure 33 reveals the same strong correspondence between the forecasted values and the RWIS observations. The MAE (3.21°C) of the VDT analysis and the RWIS observations is a promising result as it is consistent with the Dickey John analysis in which over 21,000 vehicle observations were compared to RWIS stations.

Table 11. Statistical comparison of the VDT analysis and the surface temperature forecast to the nearest RWIS observation within 2 km of the station (Table courtesy of NCAR).

	# Obs	Bias	MAE	Correlation
VDT Analysis (°C)	93	-1.10	3.21	0.92
Forecast (°C)	86	-0.95	2.03	0.92

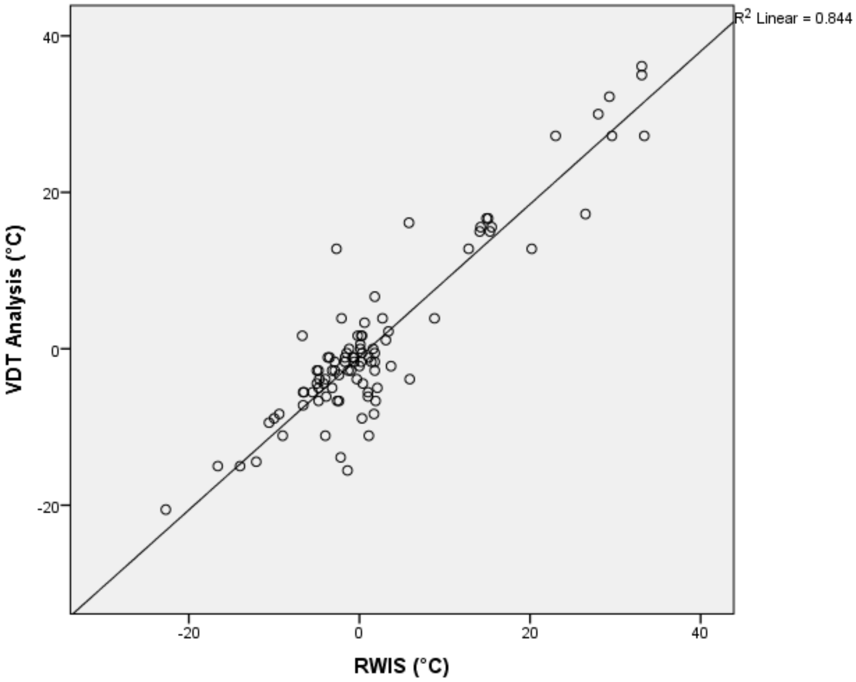


Figure 32. Scatterplot of all valid VDT analysis and RWIS observed surface temperature values within 2 km of the RWIS site (Image courtesy of NCAR).

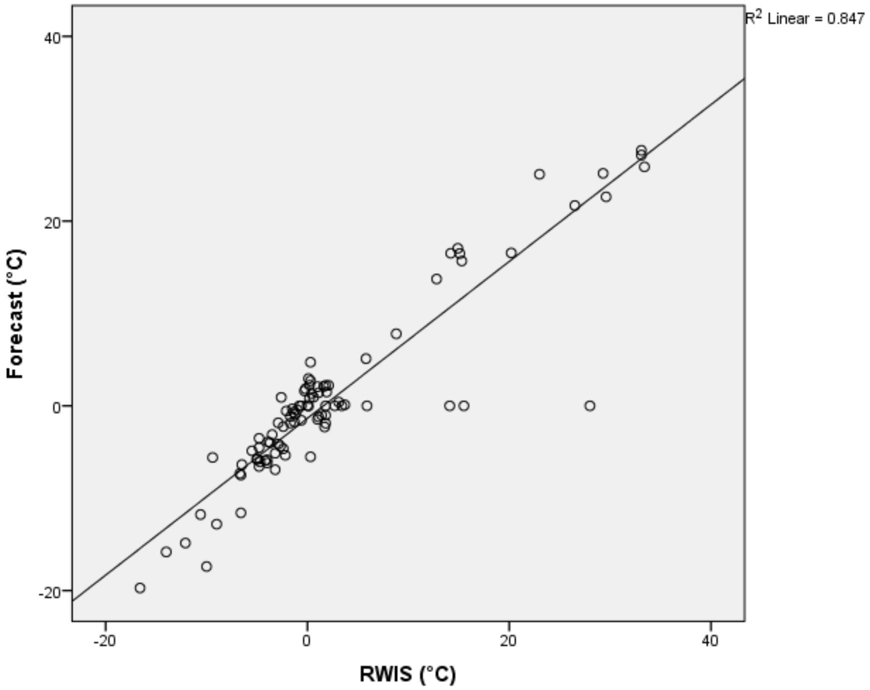


Figure 33. Scatterplot of all valid forecasted and RWIS observed surface temperature values within 2 km of the RWIS site (Image courtesy of NCAR).

Next, because the results indicated that the VDT output is reasonably consistent with RWIS surface temperature observations near the stations, the VDT analysis data were compared to the forecast values away from RWIS sites at distance intervals of 2 - 4.99 km, 5 - 9.99 km, and 10 - 20 km. The comparison of these data is given in Table 12. There is some indication of increasing variability between the forecast and the VDT analysis at greater distances. However, at the greatest distances, the MAE and the standard deviation decrease and do not significantly differ from those values observed at less than 2 km from the RWIS station. A t-test also failed to reveal a statistically reliable difference between the MAE at less than 2 km and the MAE at between 2 and 4.99 km ($p = 0.581$, $\alpha = 0.05$). The test did show a significant difference between the MAE at less than 2 km and at the interval between 5 and 9.99 km ($p = 0.008$, $\alpha = 0.05$).

Table 12 Statistical comparison of the VDT Analysis and the forecasted surface temperature at different distance intervals away from the RWIS station (Table courtesy of NCAR).

	Surface Temperature (°C)			**t-test for Equality of Means**	
	# Obs	MAE	SD	t-value	p-value (2-tailed)
< 2 km	86	3.43	3.40		
2-4.99 km	69	3.93	7.36	-0.553	0.581
5-9.99 km	118	4.89	4.16	-2.670	0.008
10-20 km	50	3.15	2.39	0.523	0.602

To further visualize the differences in the error distributions at different distance intervals, histograms of the error (forecasted pavement temperatures – VDT analysis) were generated (Figure 34). The plots reveal a clear increase in both mean and standard deviation at greater distances until the final interval of 10 - 20 km at which these values decrease.

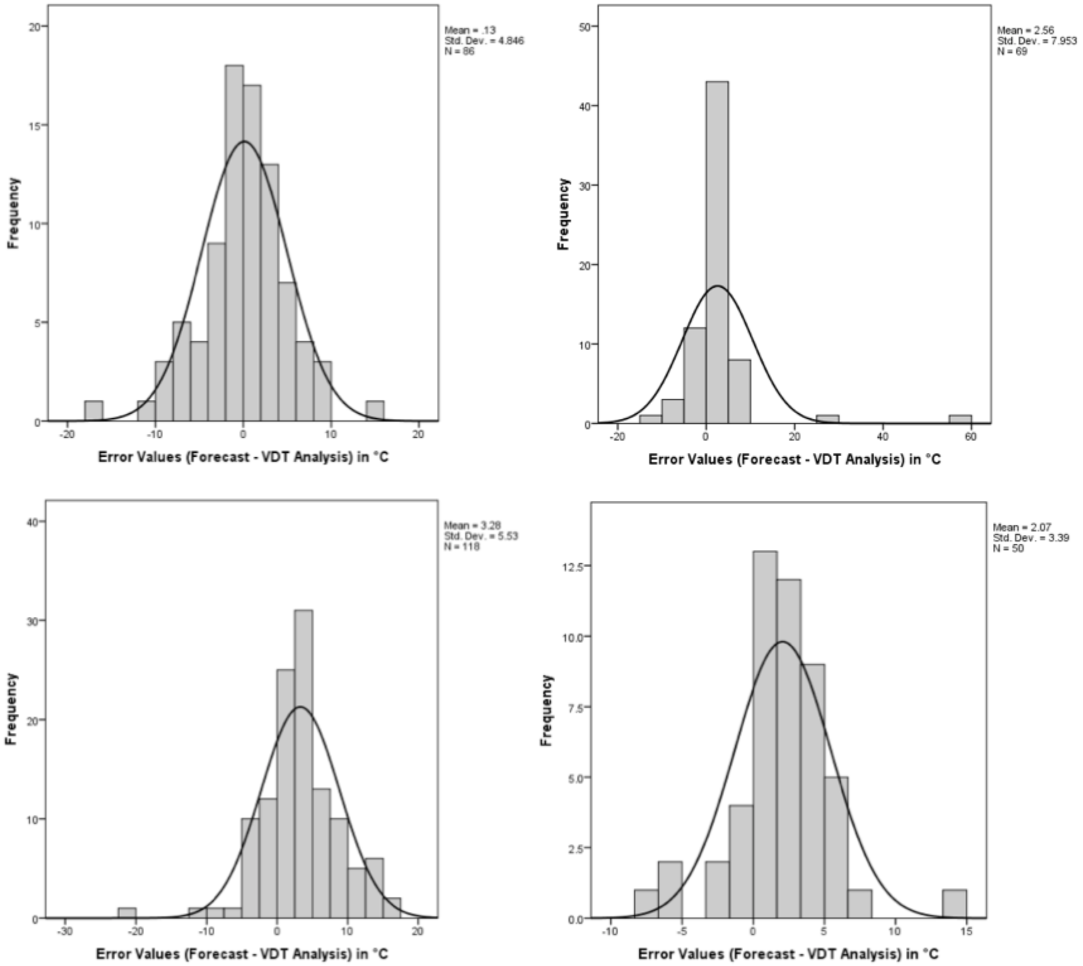


Figure 34. Frequencies of error values (VDT analysis output subtracted from forecast values) at less than 2 km (top left), between 2 and 4.99 km (top right), between 5 and 9.99 km (bottom left), and between 10 and 20 km (bottom right) (Image courtesy of NCAR).

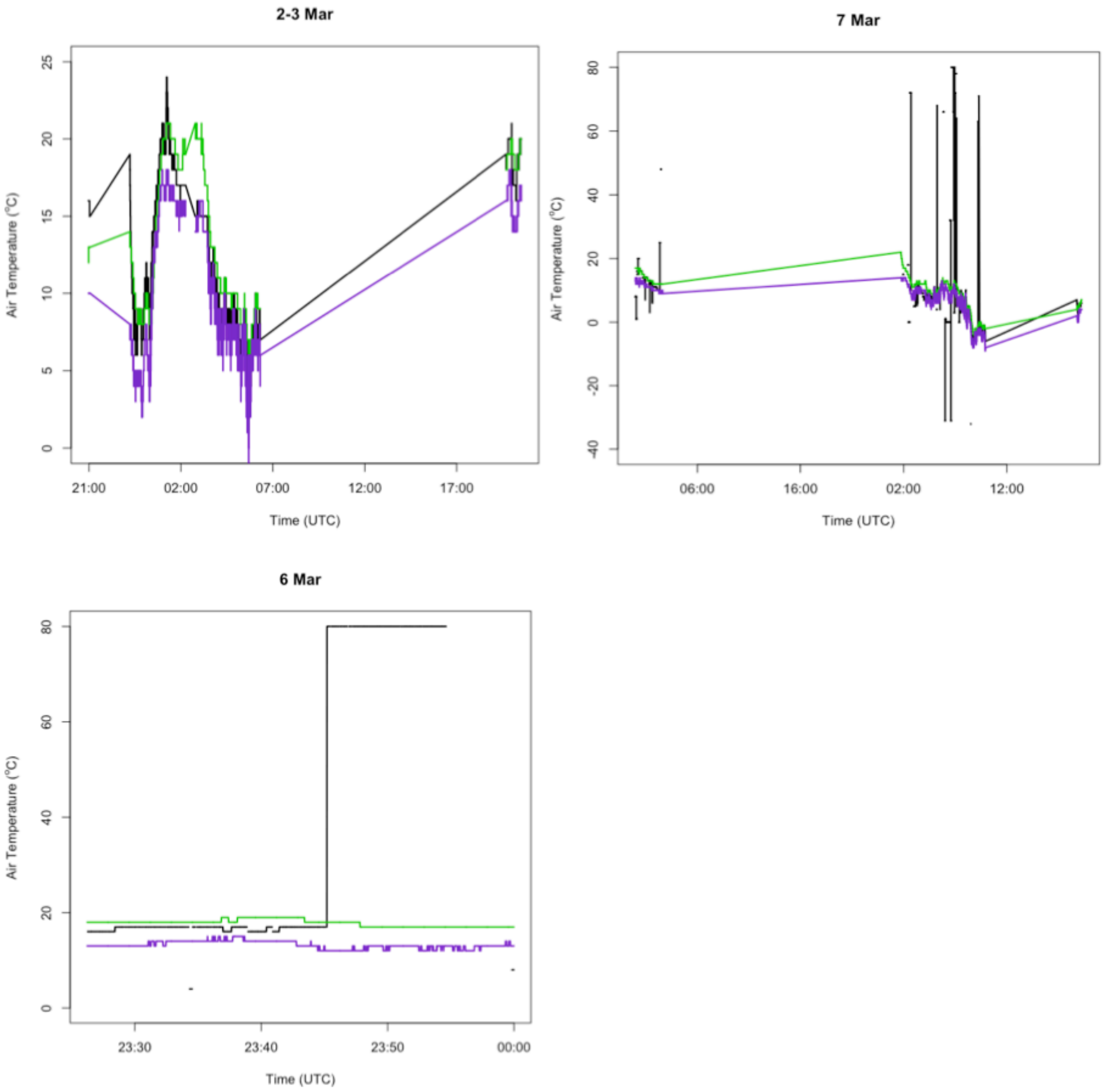
Overall, there is a consistently strong correspondence between the VDT analysis of surface temperature and what is being observed at RWIS stations. Although this correspondence cannot prove irrefutably that the VDT output would have significant value if used to forecast pavement temperatures away from RWIS sites, it is a promising result. Due to the small number of data points at each distance interval, the lack of significant change in variability, as shown in this section, between the forecast and the VDT analysis at greater distances is not necessarily conclusive. Further more robust analysis with a larger sample size is warranted.

Nevada

External Sensors

Observations were compared among the three external sensors to determine how consistent they were with one another. When available, the RoadWatch was used as the baseline for the MD and

MAD. For relative humidity, the Airmar was used as the baseline. A time series of air temperature for each time period is shown in Figure 35. Most noticeable are the outliers reported by the Surface Patrol HD, particularly the very high temperatures on 6 March and 7 March. These outliers accounted for 3.3% of non-missing observations. Otherwise, the RoadWatch appeared to report slightly warmer temperatures than the Surface Patrol HD, and the Airmar reported cooler temperatures. This is supported by the MD, which was -1.38°C with Surface Patrol HD outliers removed and -2.91°C for the Airmar. The MAD was 2.12°C and 2.93°C respectively, and the correlation was 0.83 and 0.97. Overall, the three instruments tended to be within 2°C of each other and were fairly well correlated. The biggest issues were with the Surface Patrol HD outliers and the approximately two hour period from 02:00 UTC to 04:00 UTC on 3 March, where the RoadWatch air temperature was several degrees higher than the Surface Patrol HD and Airmar temperatures (Figure 35).



2-3 Mar

7 Mar

6 Mar

Figure 35. Time series of air temperature recorded by the Surface Patrol HD (black), RoadWatch (green), and Airmar (purple) for each of the three time periods (Image courtesy of NCAR).

The surface temperatures reported by the Surface Patrol HD and RoadWatch sensors were also compared. Time series for each time period are shown in Figure 36. Far fewer outliers appeared in the surface temperature data compared with air temperature. There was generally good agreement between the sensors during the period of analysis. The MD was -0.73°C, the MAD 1.31°C, and the correlation 0.97. This indicates that although the Surface Patrol HD tended to report slightly cooler temperatures, the two instruments were very well correlated and generally within 1°C of each other.

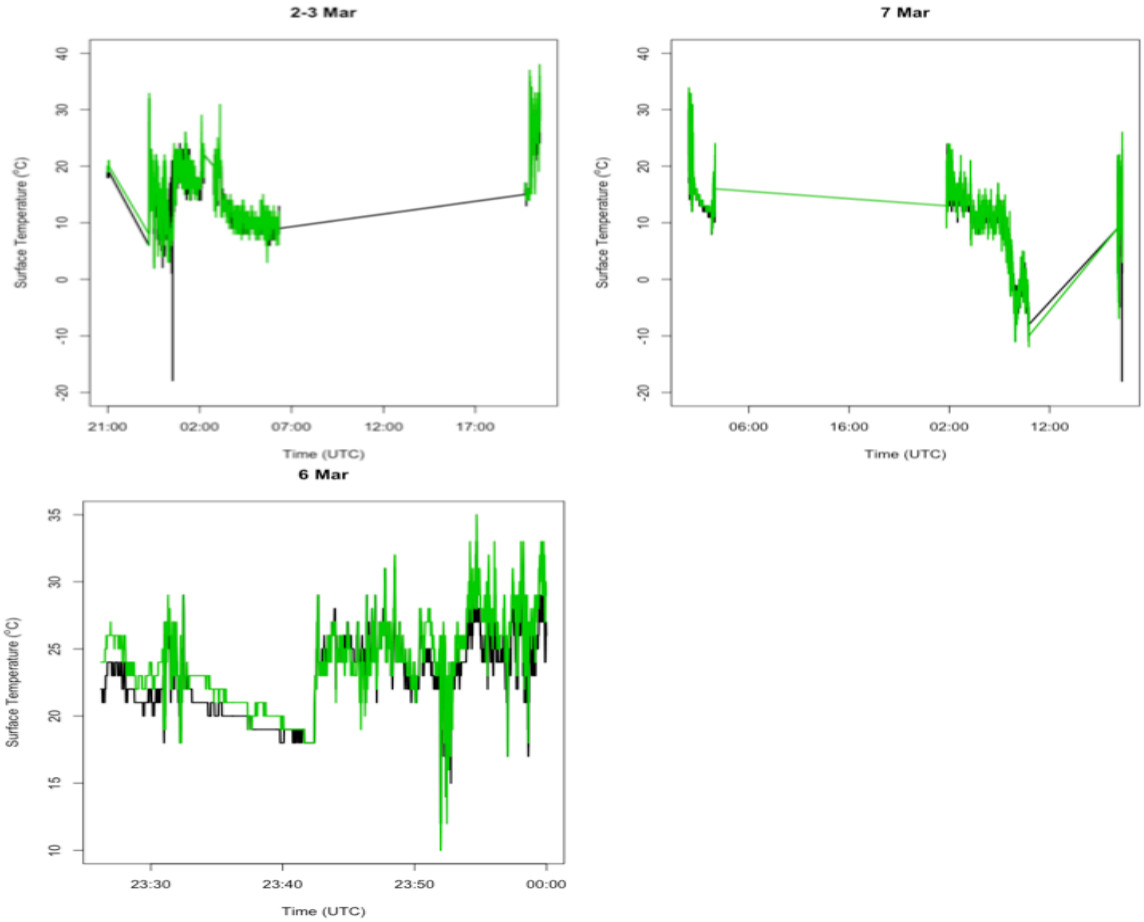


Figure 36. Time series of surface temperature recorded by the Surface Patrol HD (black) and RoadWatch (green) for each of the three time periods (Image courtesy of NCAR).

The last observation made by multiple external sensors was relative humidity, which was measured by the Surface Patrol HD and Airmar. Time series for each time period are shown in Figure 37. The two observations were generally in good agreement during the first period of 2-3 March. However, there was a clear low bias of the Surface Patrol HD in the latter half of 6 March and much more variation in the observations on 7 March compared with the Airmar. Using the Airmar as a baseline, the MD was 3.03%, MAD 7.87%, and correlation 0.45. This shows that overall the Surface Patrol HD tended to be slightly more moist and within 7% of the Airmar on average, but the two measures were poorly correlated. This may be due, in part, to the noisiness of the Surface Patrol HD measurements during the 7 March period.

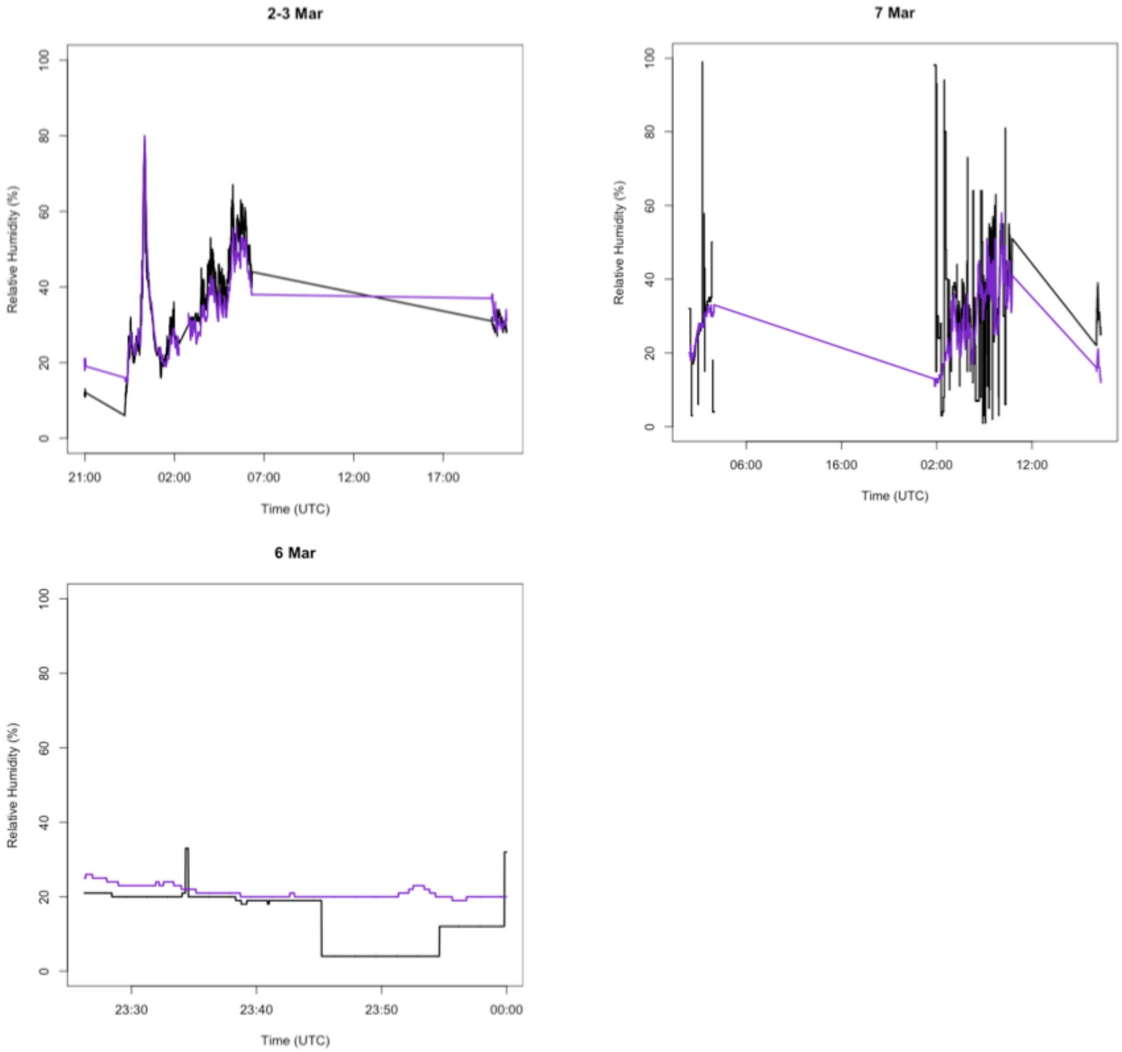


Figure 37. Time series of relative humidity recorded by the Surface Patrol HD (black) and Airmar (purple) for each of the three time periods (Image courtesy of NCAR).

Finally, the sensor observations were compared with a nearby RWIS station, which was considered to be the truth observation. For air temperature, the overall comparison was reasonable for all instruments (Table 13). The Airmar showed the closest match with the RWIS stations at a 0.30°C bias and MAE of only 2.08°C. The Surface Patrol HD and RoadWatch, though exhibiting a warm bias with the RWIS stations, were slightly different than the Airmar with an MAE of about 3.5°C each. The RoadWatch and Airmar were both highly correlated with the RWIS stations at value 0.90, but the Surface Patrol HD had a much lower correlation of only 0.53. This may have been due to the outliers noted on the time series plots. With these values removed (temperature > 40°C or < -20°C), the correlation jumped to 0.88 and MAE improved to 2.70°C.

Table 13. Statistical comparison of air temperature (°C) between the external sensors and the nearest RWIS station (Table courtesy of NCAR).

	Surface Patrol HD	RoadWatch	Airmar
Bias	2.38	3.25	0.30
Mean Absolute Error	3.73	3.56	2.08
Correlation	0.53	0.90	0.90

Surface temperature comparisons with RWIS were also favorable (Table 14). Both the Surface Patrol HD and RoadWatch exhibited a slight positive bias and were on average a few degrees off from the RWIS station observations. The correlations were very high at > 0.9.

Table 14. Statistical comparison of surface temperature (°C) between the external sensors and the nearest RWIS station (Table courtesy of NCAR).

	Surface Patrol HD	RoadWatch
Bias	1.06	2.16
Mean Absolute Error	2.93	3.86
Correlation	0.94	0.92

Relative humidities were not as closely matched between the external sensors and the nearest RWIS stations (Table 15). Both instruments had a dry bias and over 10% MAE. The Airmar had a correlation of 0.75, which is appreciable but not as closely correlated as air temperature was with the RWIS station. The Surface Patrol HD had a very low correlation of only 0.21. As noted in the time series, there were several outliers during the 7-8 March time period. Limiting the analysis to the first two time periods yielded a correlation of 0.87 between the Surface Patrol HD and nearest RWIS station, lending some credence to the supposition that the noisy data from 7-8 March was a factor in the low correlation.

Table 15 Statistical comparison of relative humidity (%) between the external sensors and the nearest RWIS station (Table courtesy of NCAR).

	Surface Patrol HD	Airmar
Bias	-4.21	-9.50
Mean Absolute Error	13.28	10.52
Correlation	0.21	0.75

The Airmar outputted barometric pressure reduced to mean sea level (MSL), without an associated station pressure. The RWIS stations report only station pressure. Because of the uncertainties related to the MSL calculation, especially incomplete moisture profile information, rather than calculating the RWIS MSL pressure to compare with the Airmar, ASOS stations were matched with the vehicle data, and the MSL pressure these stations output was used. The same matching criteria used for matching RWIS observations were used to match the ASOS observations.

The comparison between the Airmar and the ASOS stations is given in Table 16. The Airmar compared quite well with the ASOS stations, with an MAE of only 3 hPa and a high correlation of 0.88. Considering the Aimar uses GPS elevation for its sea level calculation, which is often time suspect, this is a very good result.

Table 16. Statistical comparison of barometric pressure (hPa) between the Airmar and the nearest ASOS station (Table courtesy of NCAR).

	Airmar
Bias	-1.78
Mean Absolute Error	3.20
Correlation	0.88

The Airmar also measured wind speed and direction, and these were compared with the nearest RWIS station. The Airmar measures the apparent wind speed and direction, which is the wind speed and direction relative to the moving vehicle rather than the fixed ground. The instrument then uses a built-in GPS and compass to calculate the true wind based on the apparent wind, speed of the vehicle, and compass heading. The Nevada data comes from a summary message, which includes a true wind direction, magnetic wind direction, and only one wind speed observation. This is presumed to be the true wind speed, rather than apparent, but there is no way to know this for certain without additional testing.

The statistics given in Table 17 were calculated using the wind speed in the summary message and the observation labeled true wind direction. There was a very strong positive bias and high MAE of over 30 m/s for the wind speed and a poor, negative correlation with the RWIS stations. The wind direction was also significantly different from the RWIS station observations. The bias was only slightly negative, but the MAE was very high at 121.78° and the correlation was near 0.

Table 17. Statistical comparison of wind (m/s and °) between the Airmar and the nearest RWIS station (Table courtesy of NCAR).

	Airmar Wind Speed	Airmar Wind Direction
Bias	33.64	-7.24
Mean Absolute Error	33.68	121.78
Correlation	-0.22	-0.07

These poor statistics suggest that the Airmar is either not properly correcting the wind speed and direction at the high speeds of the vehicle, or in the case of wind speed the apparent wind is the one being reported. Comparing the Airmar wind speeds with the vehicle speed shows a very strong linear relationship with vehicle speed, leading to speculation that the apparent wind may in fact be the one included in the summary message (Figure 38). It is also possible that there is a flaw in how the Airmar calculates the true wind speed from the apparent wind speed, and that the magnitude of this error is dependent on vehicle speed.

The Airmar wind direction was compared with the vehicle heading to determine if a similar linear relationship existed with the vehicle movement as with the Airmar wind speed. This is shown in Figure 39. There is no clear linear dependence on wind direction with heading as was seen on wind speed with vehicle speed, but two areas of the image do stick out as having a linear relationship. These are marked with the solid blue lines in Figure 39. Although not as obvious as with wind speed, it does appear that the true wind direction has, in some cases, a slight linear dependence on vehicle heading.

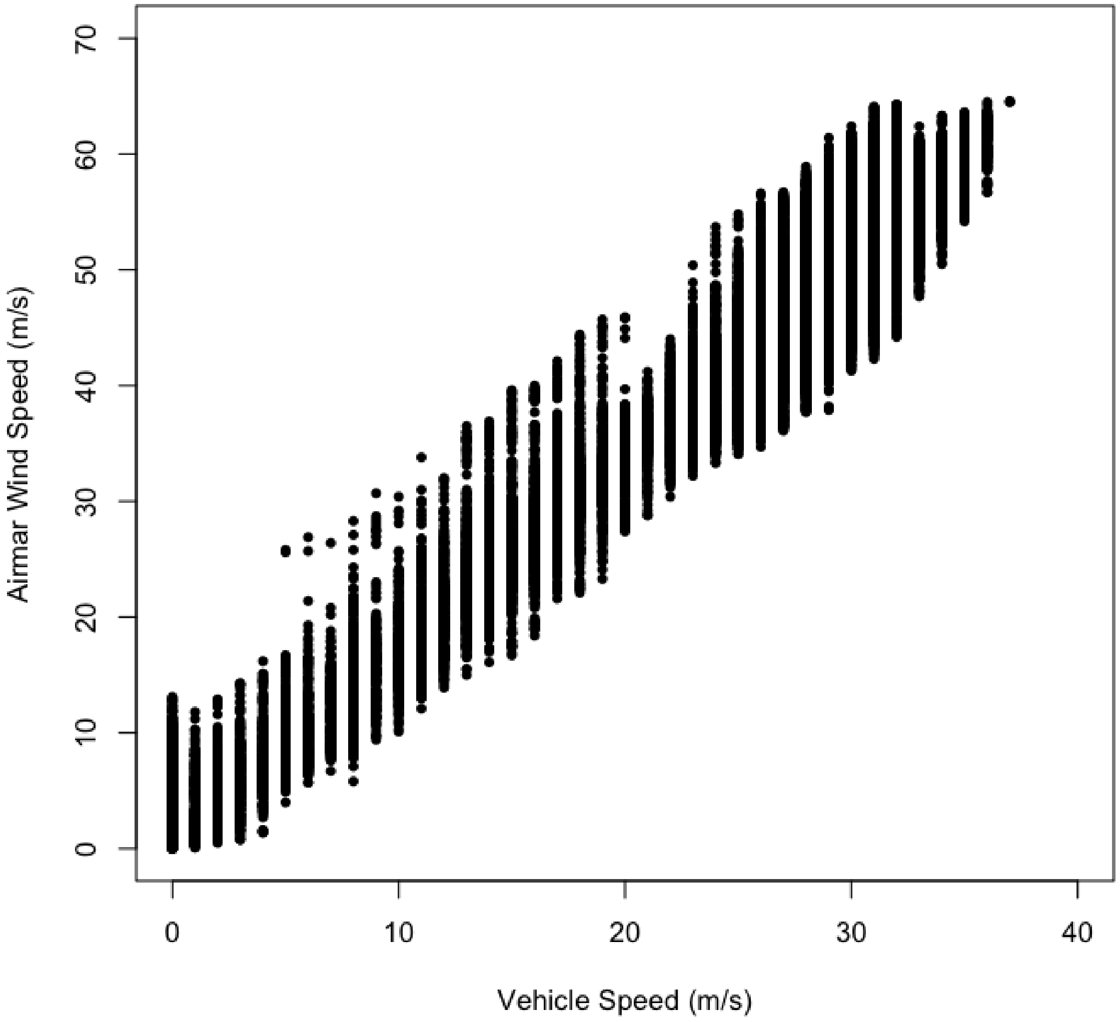


Figure 38. Vehicle speed versus Airmar wind speed over the entire case period (Image courtesy of NCAR).

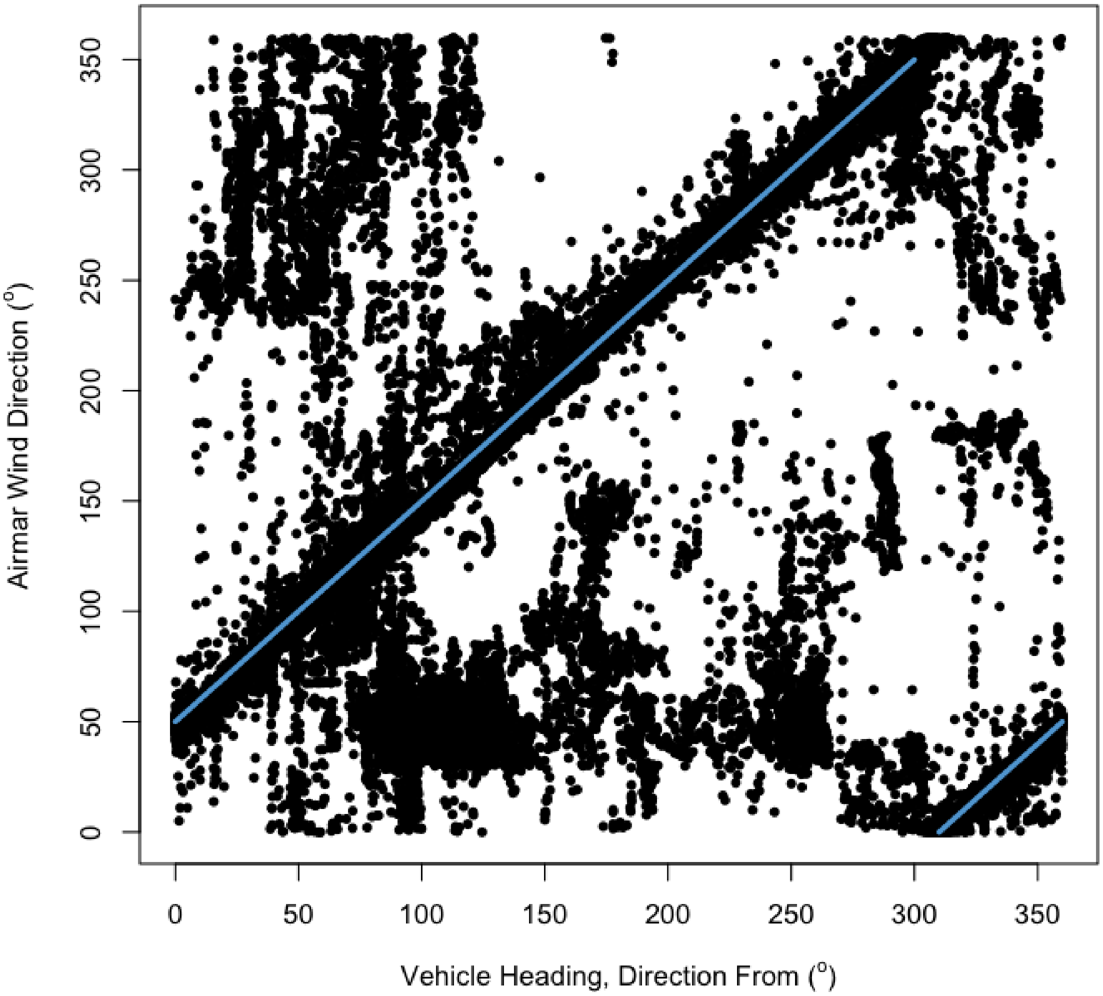


Figure 39. Vehicle heading versus Airmar wind direction over the entire case period. Blue lines indicate the linear relationships existing in the data that are discussed in the text (Image courtesy of NCAR).

In order to control for these linear relationships between vehicle movement and calculated wind speed/direction, additional statistics were run for when the vehicle was not moving (Table 18). The wind speed statistics are much improved, with only a slightly positive bias and an MAE of only 1.5 m/s. The correlation was also much higher at 0.84. However, there was very little improvement in the wind direction statistics. The negative bias was slightly stronger, the MAE only lowered by about 10°, and there was a near-zero correlation.

Table 18. Same as Table 17, but for 0 m/s vehicle speed only (Table courtesy of NCAR).

	Airmar Wind Speed	Airmar Wind Direction
Bias	1.39	-17.24
Mean Absolute Error	1.54	110.25
Correlation	0.84	-0.17

Overall, the air and surface temperatures of the external instruments seemed reliable within about 2-3°C of the true temperature. The Airmar and RoadWatch were more consistent in reporting valid numbers than the Surface Patrol HD, which reported many invalid observations (particularly for air temperature) and tended to be noisy at times. The relative humidity was not as well correlated between instruments and the RWIS stations, particularly the noisy values of the Surface Patrol HD. Mean sea level air pressure from the Airmar correlated well with the ASOS stations. The Airmar wind speed does not appear to be reported as the true wind, but rather the apparent, and wind direction is poorly correlated with the RWIS stations for both a moving and stationary vehicle.

CANbus

Statistical comparison of the non-missing observations with the nearest RWIS station is given in Table 19. It is clear from this table that neither vehicle-based observation is representative of the conditions observed by the RWIS stations. The air temperature reported by the CANbus was an intake air temperature, meaning rather than being located in the front grill of the vehicle the sensor was located in the engine compartment, making the measurement much less representative of the actual atmospheric air temperature. Correlation was also low.

The barometric pressure was reported in a coarse 10-hPa resolution, which in addition to making the measurements impractical for meteorological applications (Drobot et al. 2009) could also explain part of the high MAE. However, the large magnitude of this MAE cannot be fully explained by this resolution issue. It is important to note that the negative leaning of the bias is due to several observations occurring on and after 23 May (Figure 40). Because of these clearly erroneous observations, the remaining pressure statistics in this section do not include these dates. Table 19 shows the large change in the statistics with these values removed. The bias and MAE are still very high (40.85 and 50.11 respectively), but there is an improvement in the MAE compared to that which includes the erroneous end of May values, and the correlation jumps to 0.49, closer in line with the air temperature correlation. These statistics are also much more representative of the entire analysis period than those that include the end of May observations.

Table 19. Statistical comparison of vehicle-observed intake air temperature (°C) and barometric pressure (hPa) with nearest RWIS station (Table courtesy of NCAR).

	Bias	MAE	Correlation
Air Temperature	18.30	19.85	0.41
Barometric Pressure	-4.11	88.43	0.12
Barometric Pressure (before 23 May)	40.85	50.11	0.49

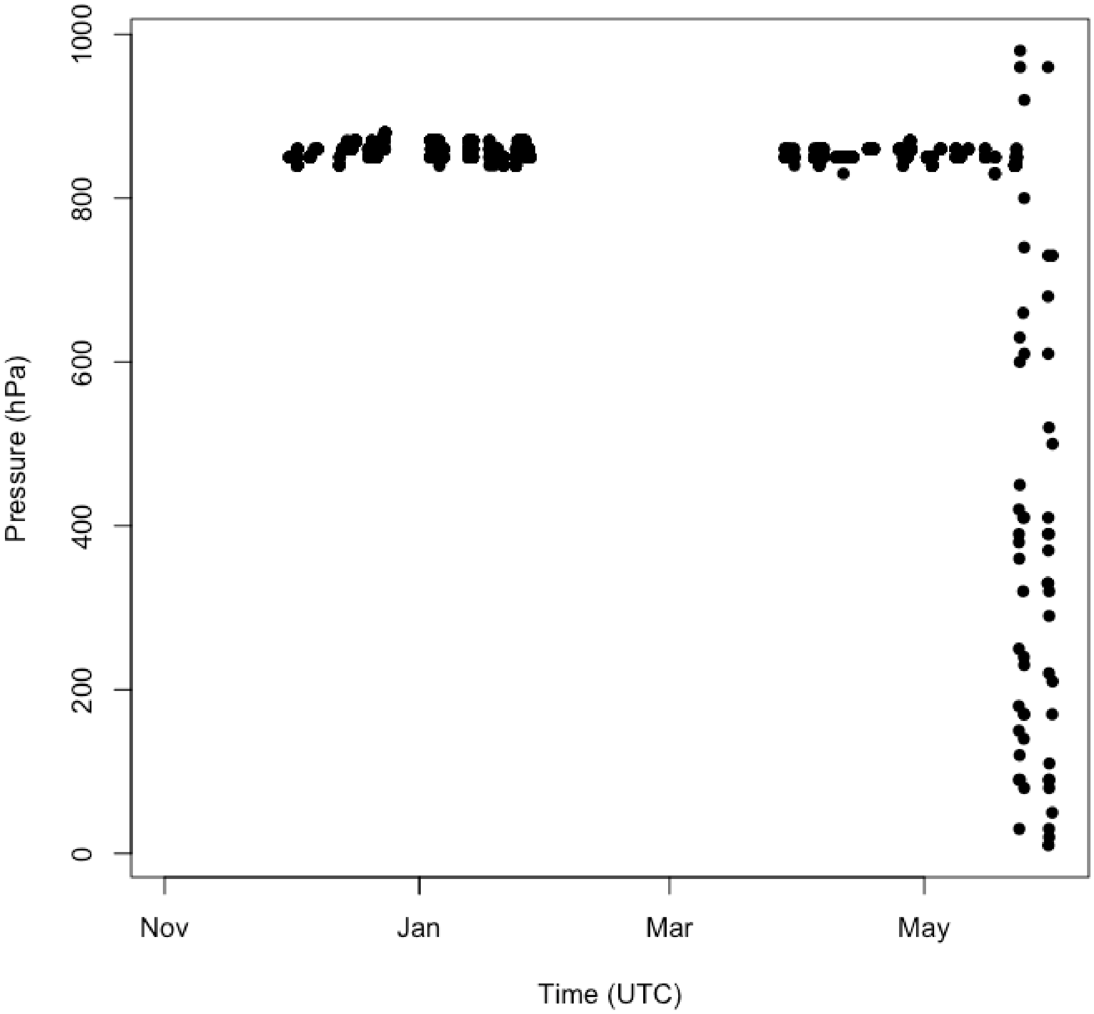


Figure 40. Time series of all valid barometric pressure observations (i.e., with 0 hPa and 2550 hPa values removed) (Image courtesy of NCAR).

To further explore the comparison between the vehicles and RWIS stations and determine if certain vehicles or conditions degraded the CANbus observations, the statistical calculations were stratified by the following factors: vehicle, ambient air temperature, date, and time of day. Additionally, pressure calculations were stratified by RWIS station-observed pressure in order to determine if the VDT's lack of an elevation criterion for matching the nearest station had a significant impact on the statistics.

Typically the VDT strips vehicle identification information for privacy purposes. However, for this dataset, vehicle identification information was retained, and the stratification by vehicle is shown in Table 20. Immediately obvious is the overwhelming data contribution by vehicles A1 and A2 for intake air temperature. Vehicles A4, C2, C3, C11, and C12 contributed less than 100 data points each (with some contributing less than 10). The remaining vehicles had no valid observations reported. Additionally, only vehicle A1 reported valid pressure observations.

For air temperature, the only variable to have valid observations reported by more than one vehicle, the A vehicles have a clearly higher bias and MAE compared with the C vehicles. However, with so few observations reported by the C vehicles, it is difficult to draw any conclusions from this.

Table 20. Statistical comparison of vehicle-observed intake air temperature (°C) and barometric pressure (hPa) with nearest RWIS station, stratified by vehicle (Table courtesy of NCAR).

	Air Temperature				Barometric Pressure			
	# Obs	Bias	MAE	Correlation	# Obs	Bias	MAE	Correlation
0682	0	n/a	n/a	n/a	0	n/a	n/a	n/a
3319	0	n/a	n/a	n/a	0	n/a	n/a	n/a
3320	0	n/a	n/a	n/a	0	n/a	n/a	n/a
A0	0	n/a	n/a	n/a	0	n/a	n/a	n/a
A1	1828	17.95	20.44	0.26	466	40.85	50.11	0.49
A2	1360	20.36	20.36	0.77	0	n/a	n/a	n/a
A4	8	28.61	28.61	-0.93	0	n/a	n/a	n/a
A11	0	n/a	n/a	n/a	0	n/a	n/a	n/a
B1	0	n/a	n/a	n/a	0	n/a	n/a	n/a
B2	0	n/a	n/a	n/a	0	n/a	n/a	n/a
C2	76	2.77	6.28	n/a	0	n/a	n/a	n/a
C3	10	6.70	-6.70	n/a	0	n/a	n/a	n/a
C11	1	0.89	0.89	n/a	0	n/a	n/a	n/a
C12	46	0.80	5.33	n/a	0	n/a	n/a	n/a
E1	0	n/a	n/a	n/a	0	n/a	n/a	n/a

Note that 0 observations indicate that there were no non-missing observations collected from that vehicle, and some vehicles with few observations have no correlation because those few observations were collected in a small timeframe, meaning only one unique RWIS station observation could be attached to them.

The statistics were also stratified by ambient air temperature, as observed by the nearest RWIS station, to see if the temperature condition affected the sensors' abilities to accurately measure intake air temperature and barometric pressure (Table 21). Intake air temperature observations tended to have a slightly lower bias/MAE closer to the freezing point (0°C), but the difference was only a few degrees. There tended to be lower (more negative) bias for barometric pressure for warmer values, although it could be that the RWIS station was at a lower elevation/warmer temperature than the vehicle itself at those times. Additional data and analysis is warranted to determine if there is a causal link between warmer temperatures and lower pressures measured by the vehicle.

Table 21. Statistical comparison of vehicle-observed intake air temperature (°C) and barometric pressure (hPa) with nearest RWIS station, stratified by RWIS station-observed air temperature (Table courtesy of NCAR).

	Air Temperature				Barometric Pressure			
	# Obs	Bias	MAE	Correlation	# Obs	Bias	MAE	Correlation
< -20°C	0	n/a	n/a	n/a	0	n/a	n/a	n/a
-20 – -15°C	9	20.49	20.49	-0.02	0	n/a	n/a	n/a
-15 – -10°C	25	22.91	22.91	-0.04	0	n/a	n/a	n/a
-10 – -5°C	179	17.23	17.23	0.29	9	55.61	55.61	-1.00
-5 – 0°C	680	19.82	19.82	0.17	136	45.29	52.54	0.38
0 – 5°C	924	14.22	15.88	0.07	199	49.54	49.54	0.76
5 – 10°C	658	18.91	21.55	0.12	67	37.70	51.38	0.63
10 – 15°C	527	21.68	23.87	0.13	32	1.71	36.52	0.57
15 – 20°C	250	21.51	22.64	0.19	19	14.06	47.59	0.97
≥ 20°C	77	15.61	21.55	-0.32	4	-82.19	82.19	-1.00

See note in Table 20 for explanation of uncalculated statistics (n/a).

Stratification by date can be seen in Figure 41 for intake air temperature and Figure 42 for barometric pressure. These plots show not only patterns in the statistics by date, but also timing and amount of valid data collected.

First, for intake air temperature, the frequency of valid data collection prior to the middle of March 2012 was spotty, as seen in Figure 41. Valid data were first collected in the beginning of December, then again on a few days in early January before more frequent collection days for the rest of the month. February and early March were again spotty until consistent collection occurred again in the middle of March through the end of the period. The largest amounts of observations per day were collected in April (light blue to cyan colors), although a couple days in January had a large number of valid observations (red and cyan bars). Collection of valid barometric pressure observations was significantly spottier than valid air temperature (Figure 42), although similar patterns of increased frequency and amount of observations per day observed in mid January and April are still apparent.

Second, the highest bias and MAE values for intake air temperature were observed in December and early January. These values were much lower after that period until about mid March, where they once again increased and were steadily in the 20°C – 30°C range for the rest of the period. In April, where there were more valid observations per day, the errors tended to be slightly lower. For the most part, though, the observations are not very representative of the RWIS station-observed temperature for the majority of the days.

The barometric pressure observation errors tended to be steady through the days (Figure 42), although those from early January had negative as opposed to positive biases and slightly higher errors. The issues with pressure observations in May that were noted at the beginning of this section are very obvious in the figure with negative biases approaching 400 and 500 hPa. Unlike with intake air temperature, there is no indication that a larger number of observations on a particular day reduces the error.

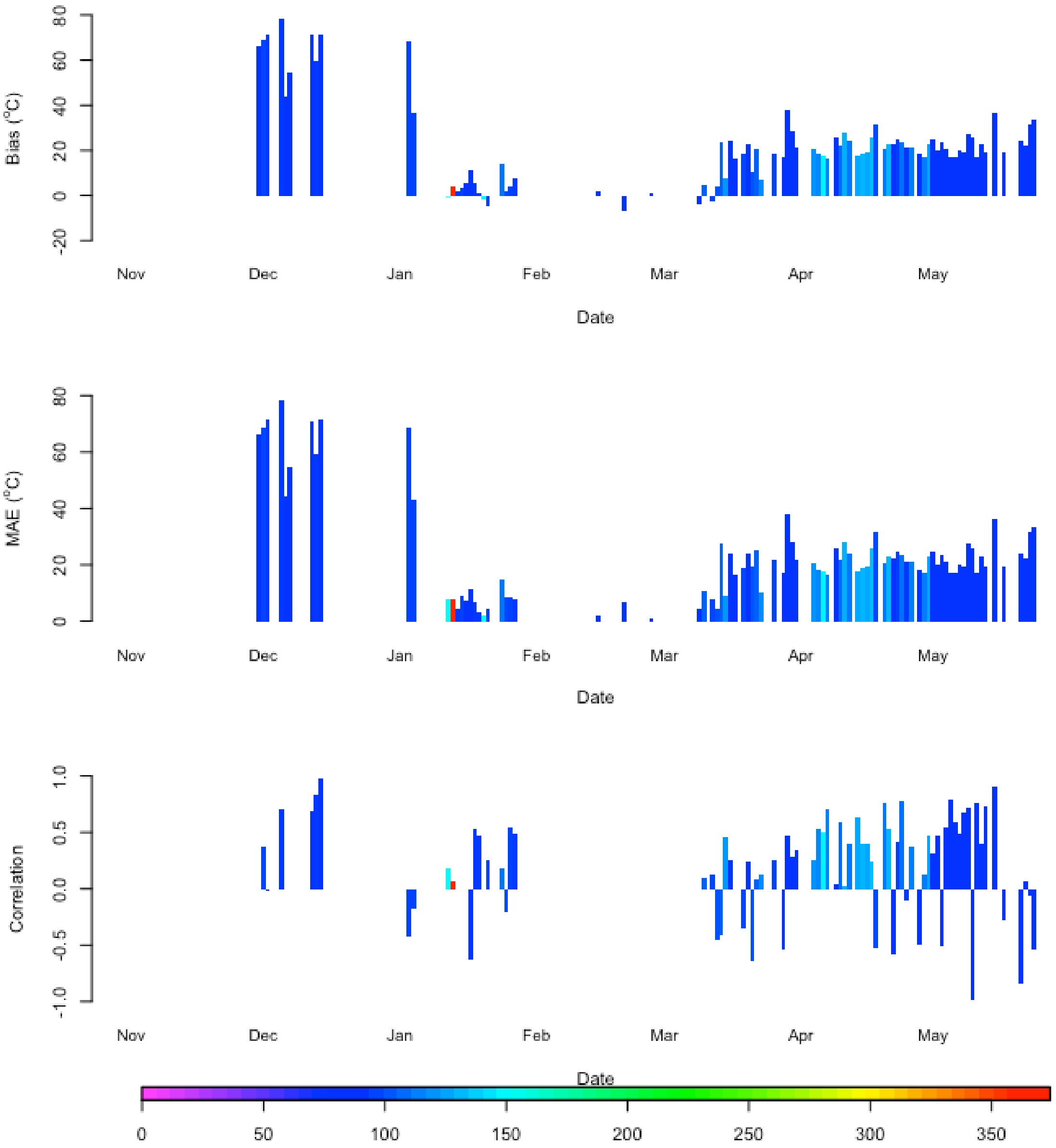


Figure 41. Statistics of vehicle-observed intake air temperature compared to the RWIS station observations, stratified by date. Colors indicate number of observations included in the statistic. Dates with no bars indicate there were no valid observations for that date (Image courtesy of NCAR).

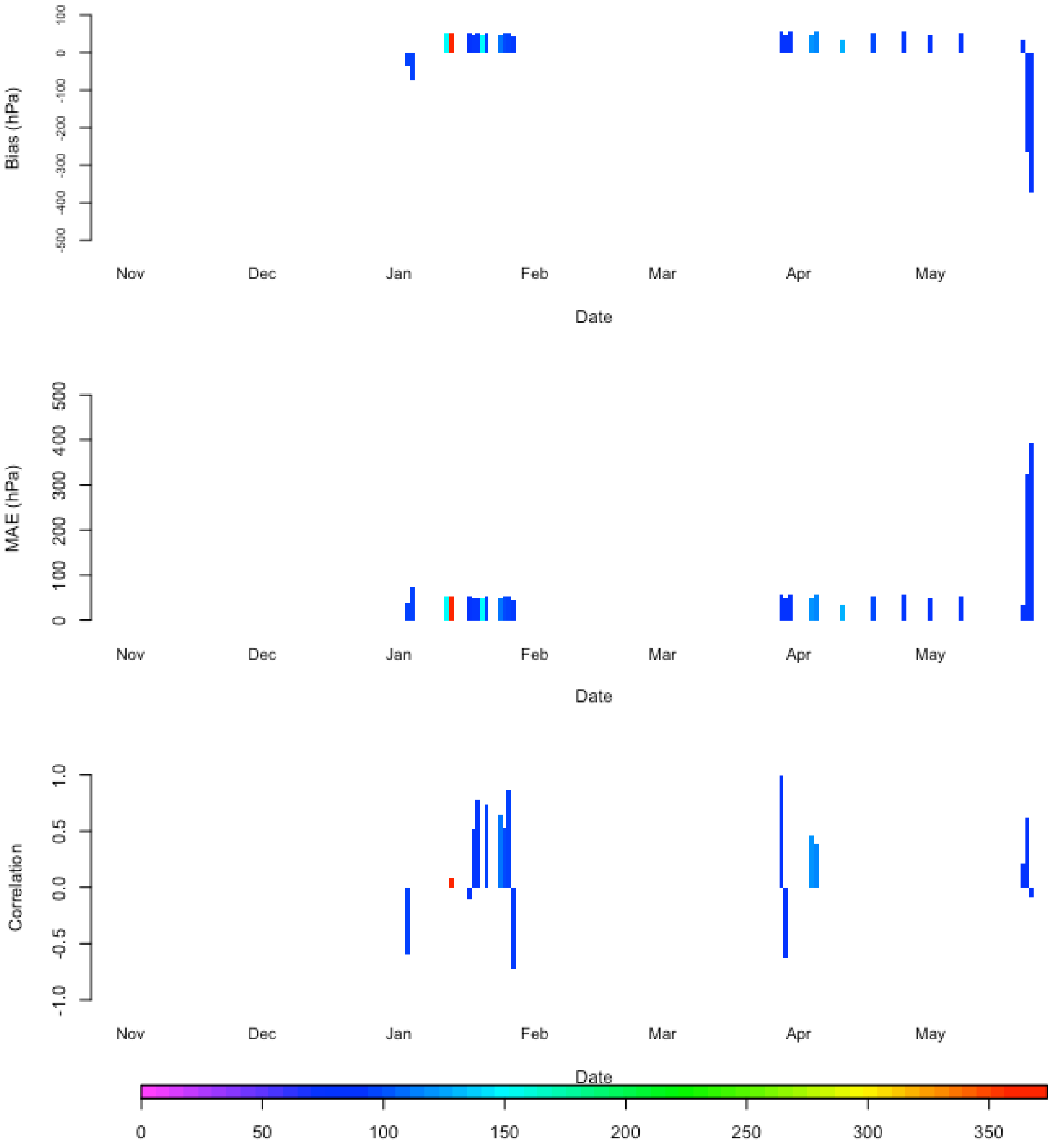


Figure 42. Same as Figure 41, but for barometric pressure (Image courtesy of NCAR).

In addition to day, the observations were also stratified by time of day (Table 22), which can indicate trends with the diurnal cycle. There is some difficultly in interpreting these results during the early morning hours, as there were very few observations available (09 – 13 UTC, or 01 – 05 PST). However, during these hours the intake air temperature errors are markedly improved over the errors at other times, which are steadily between 15° and 20°C. For barometric pressure, there was no noticeable trend with time of day.

Table 22. Statistical comparison of vehicle-observed intake air temperature (°C) and barometric pressure (hPa) with nearest RWIS station, stratified by hour of day (UTC) (Table courtesy of NCAR).

	Air Temperature				Barometric Pressure			
	# Obs	Bias	MAE	Correlation	# Obs	Bias	MAE	Correlation
00	113	16.45	17.00	0.82	15	49.43	49.43	0.96
01	119	17.60	19.16	0.63	15	50.23	50.23	n/a
02	64	15.17	16.27	0.54	15	46.90	46.90	-0.22
03	117	15.95	16.70	0.63	5	47.70	47.70	n/a
04	128	15.16	16.18	0.45	17	48.38	48.38	0.38
05	113	14.86	15.13	0.50	19	47.86	47.86	0.92
06	105	13.43	14.43	0.23	20	49.85	49.85	0.88
07	25	4.91	6.94	-0.38	15	53.90	53.90	1.00
08	15	12.29	13.86	-0.08	10	53.00	53.00	1.00
09	10	6.20	7.70	-0.99	5	48.50	48.50	n/a
10	5	-1.70	1.70	n/a	5	48.40	48.40	n/a
11	3	-2.30	2.30	n/a	3	48.20	48.20	n/a
12	5	-2.30	2.30	n/a	5	48.50	48.50	n/a
13	19	6.47	7.83	0.20	8	49.93	49.93	1.00
14	89	18.04	18.62	0.60	14	51.46	51.46	0.97
15	242	16.87	17.91	0.36	30	10.03	55.25	0.89
16	335	18.47	20.01	0.26	40	43.59	59.52	0.32
17	311	18.88	20.75	0.28	40	28.33	54.44	0.32
18	275	19.08	21.13	0.26	30	47.22	47.22	-0.57
19	242	21.38	22.94	0.18	38	49.52	49.52	-0.38
20	307	22.76	24.58	0.41	45	26.99	39.31	0.66
21	343	17.54	20.57	0.41	46	34.94	50.60	0.55
22	206	20.64	22.37	0.43	21	47.99	47.99	0.51
23	138	23.25	23.42	0.43	5	47.30	47.30	n/a

Finally, to examine the large errors in barometric pressure, this observation was stratified by RWIS station-observed pressure (Table 23). At lower RWIS station pressures (< 830 hPa), the vehicles had large positive biases, whereas at higher pressures (> 890 hPa), the vehicles had large negative biases. Additionally, although there were only 10 matched vehicle and RWIS station observations that fit this category, the bias was much lower (6.66 hPa) in the 850 – 870 hPa range. Although more analysis would need to be done to confirm this trend, it appears that at least part of the large pressure errors is due to the complex terrain of Nevada, with the nearest RWIS stations being at higher or lower elevations (lower and higher pressures) than the vehicles.

Table 23 Statistical comparison of vehicle-observed barometric pressure (hPa) with nearest RWIS station (Table courtesy of NCAR).

	#Obs	Bias	MAE	Correlation
<810	362	49.42	49.42	0.39
810-830	63	51.37	51.37	0.44
830-850	0	n/a	n/a	n/a
850-870	10	6.66	6.66	n/a
870-890	0	n/a	n/a	n/a
890-910	5	-37.00	37.00	n/a
910-930	17	-53.57	53.57	n/a
930-950	0	n/a	n/a	n/a
950-970	5	-98.66	98.66	n/a
970-990	2	-124.28	124.281	n/a
>990	2	-159.30	159.30	n/a

The road segment statistics of intake air temperature and barometric pressure produced by the VDT were also examined to determine if there were any significant differences when comparisons were made using a segment statistic as opposed to individual vehicle observations. Because the road segment data combines information from vehicles along a segment, there was no way to control for any light duty truck information that may be included.

Of 1,121 total road segments, 326 had missing observations (29.1%). The same removal of erroneous air temperature and barometric pressure values done with the probe messages was also done for the road segments, and an additional 48 air temperature and 568 barometric pressure segments were removed from the analysis (4.3% and 50.7% respectively).
Statistics comparing the road segment mean intake air temperature and barometric pressure with the closest RWIS station observation are found in Table 24. Comparison with Table 19 shows that, as expected, the road segment statistics are similar to the individual probe message statistics. There is a reduced impact from the erroneous pressures reported on and after 23 May when using road segments.

Table 24. Same as Table 19, but using road segment statistics output from the VDT (Image courtesy of NCAR).

	Bias	MAE	Correlation
Air Temperature	20.70	21.66	0.33
Barometric Pressure	25.25	67.64	0.11
Barometric Pressure (before 23 May)	38.32	53.61	0.49

Overall, neither the intake air temperature nor barometric pressure reported by the vehicles were representative of the RWIS station-observed atmospheric conditions. For intake air temperature, this likely is due to the placement of the sensor. For barometric pressure, the coarse reporting resolution and complex terrain of the area of study likely played a role in the observed errors. However, it is uncertain whether these are the sole causes of the large errors. In addition to the quality issues of the valid data, there were many missing or invalid observations gathered from the vehicle CANbus, such that the majority of valid observations were reported by a very small number of the total vehicles that were reporting.

Point vs. Segment

Air temperature

There is a strong association between point and segment-based mean CANbus air temperatures (Figure 43). The correlation coefficient is 0.91, with a mean difference of -0.03°C. The mean absolute deviation is 3.10°C, much smaller than Minnesota, and based on a series of only a few large differences between air temperature data in a given segment (e.g., Figure 44). The difference between the point and segment mean air temperature is 0°C in 40% of the cases; 32% of the cases have a point observation below the segment mean, and 27% have a point observation higher than the segment mean.

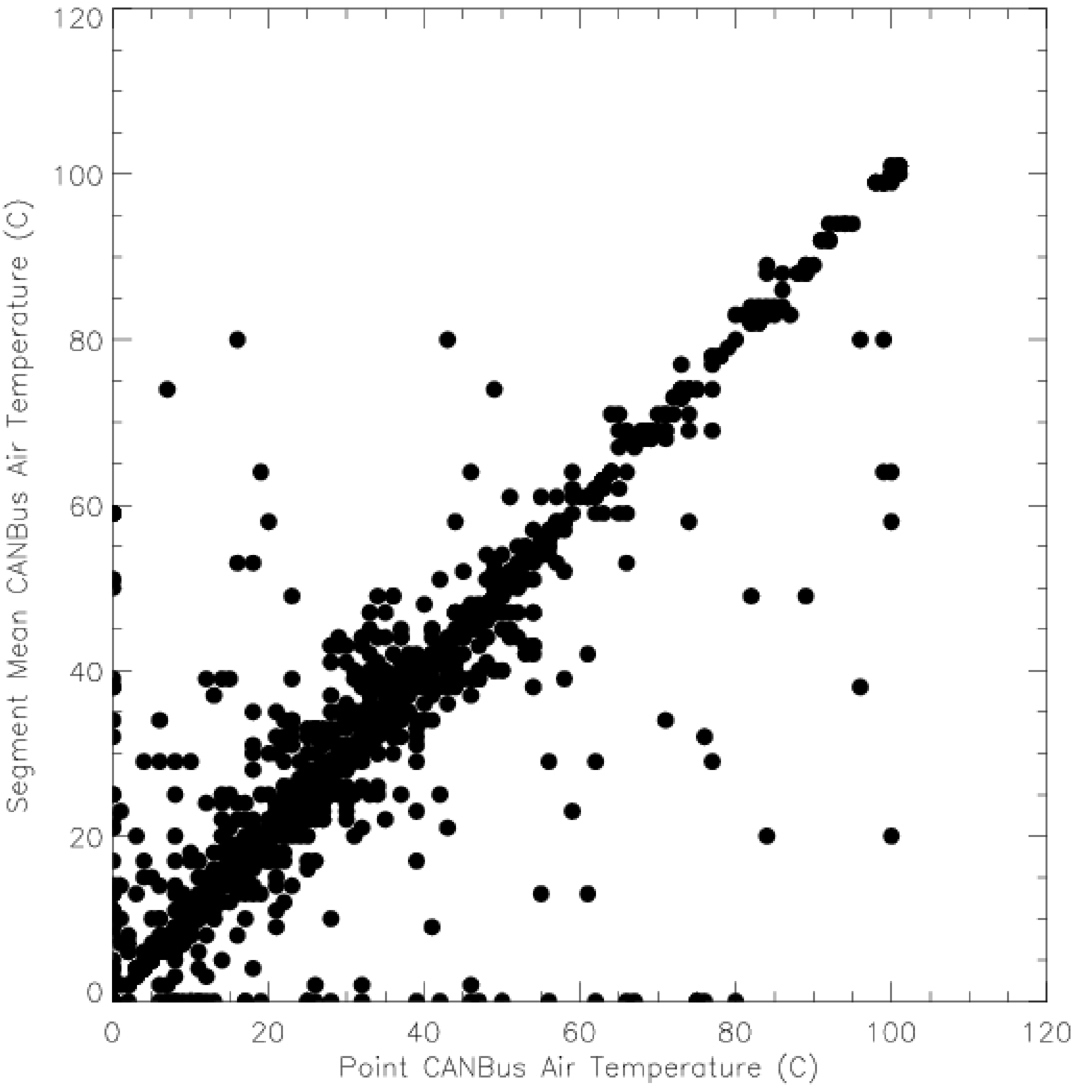


Figure 43. Nevada CANbus air temperature, point vs. segment mean (Image courtesy of NCAR).

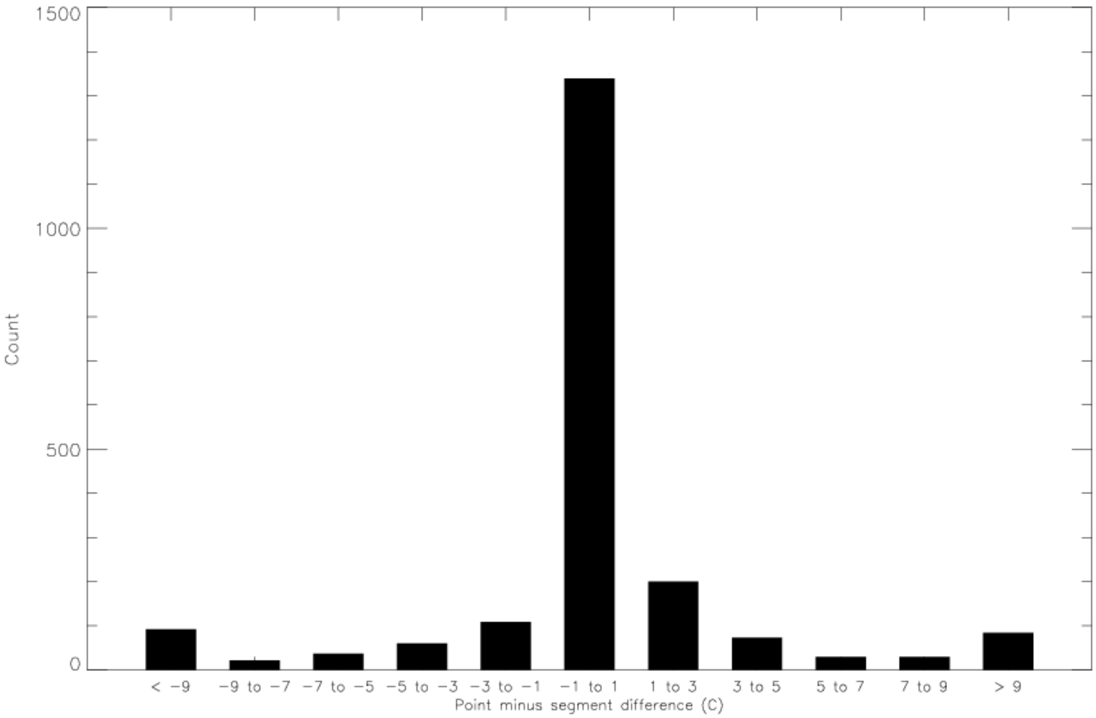


Figure 44. Nevada CANbus air temperature differences, point vs. segment mean (Image courtesy of NCAR).

Barometric pressure

Barometric pressure CANbus observations have historically lacked precision and accuracy (e.g., Chapman et al. 2010, Anderson et al. 2012). The lack of precision carries a cost in this analysis as well; the correlation between the point and segment-based mean is only 0.58, in part because of the coarse resolution (Figure 45). However, the MD (0.15 hPa) and the MAD (0.58 hPa) are approximately an order of magnitude below the sensor resolution, indicating close correspondence between the point and segment-based data. In the vast majority of cases (97%), the point and segment data are the same (Figure 46). In 2% of the cases, the point measurement is below the segment-based mean, and in the remaining 1% of cases, the point measurement is higher than the segment-based mean.

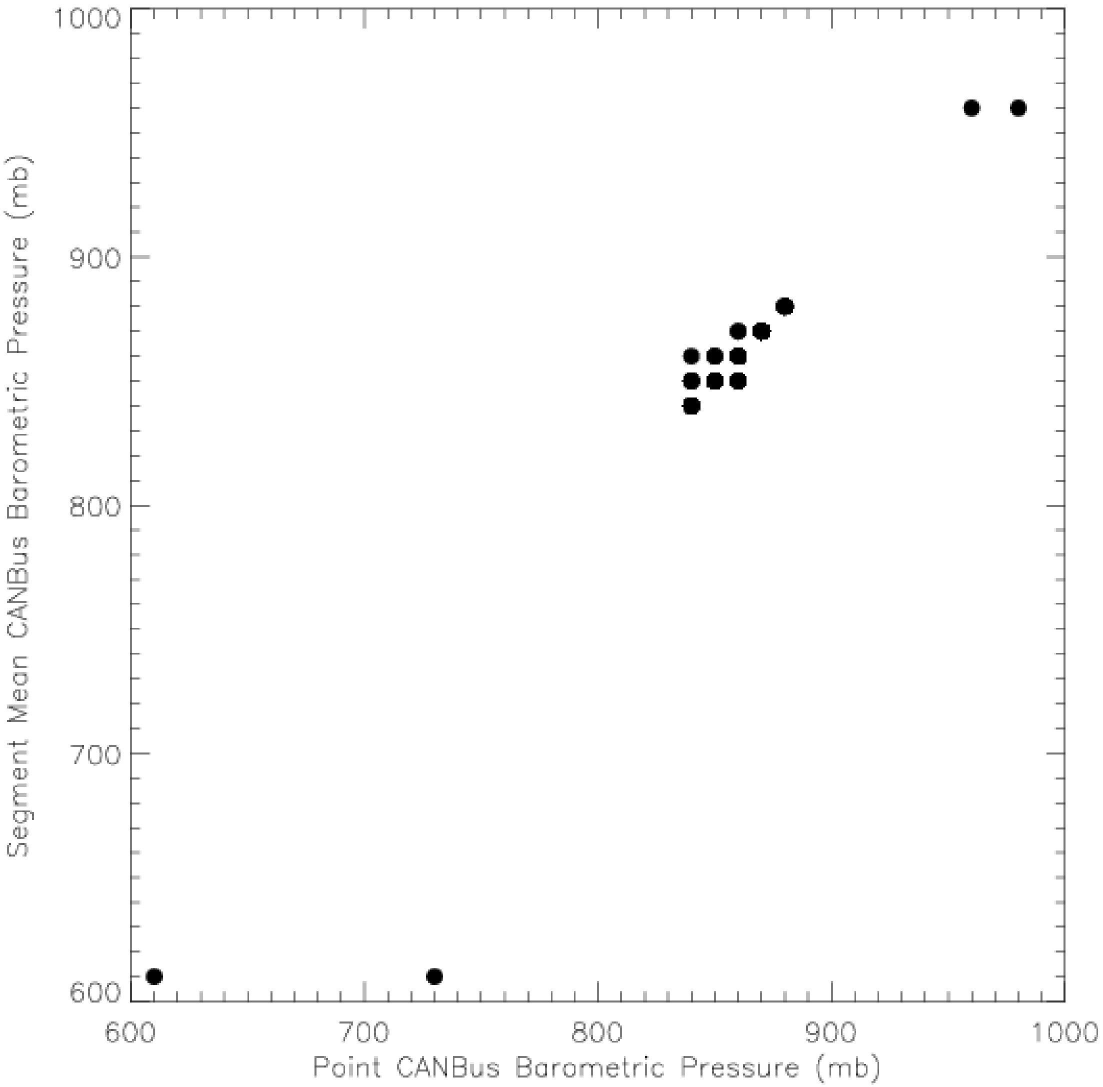


Figure 45. Nevada CANbus barometric pressure, point vs. segment mean (Image courtesy of NCAR).

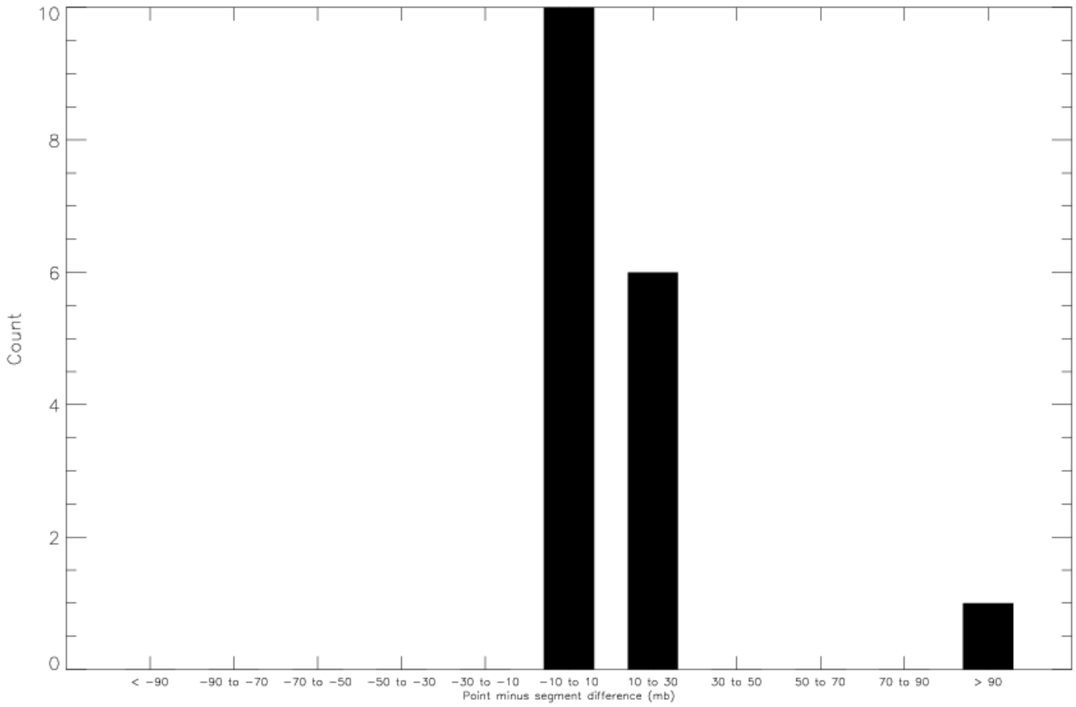


Figure 46. Nevada CANbus barometric pressure differences, point vs. segment mean (Image courtesy of NCAR).

External data

Air temperature

Compared to Nevada CANbus and Minnesota air temperatures, the external air temperature data show an even higher correspondence between point and segment-based mean observations (Figure 47). The correlation coefficient is 0.99, with a mean difference of -0.05°C and a mean absolute difference of 1.13°C. In 54% of the cases, the point and segment data are identical (Figure 48), with the point observation being higher (lower) than the segment-based observation 24% (23%) of the time.

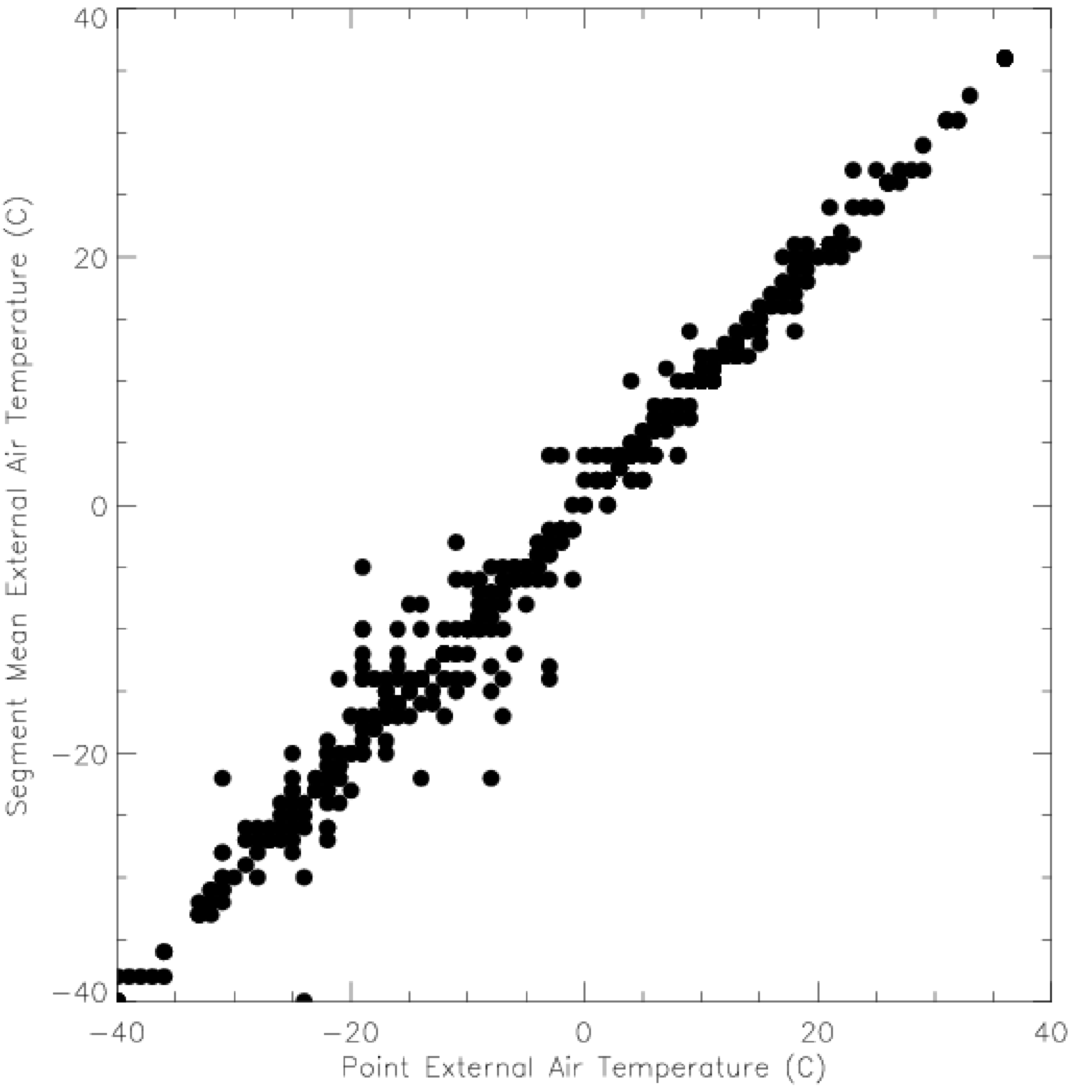


Figure 47. Nevada external air temperature, point vs. segment mean (Image courtesy of NCAR).

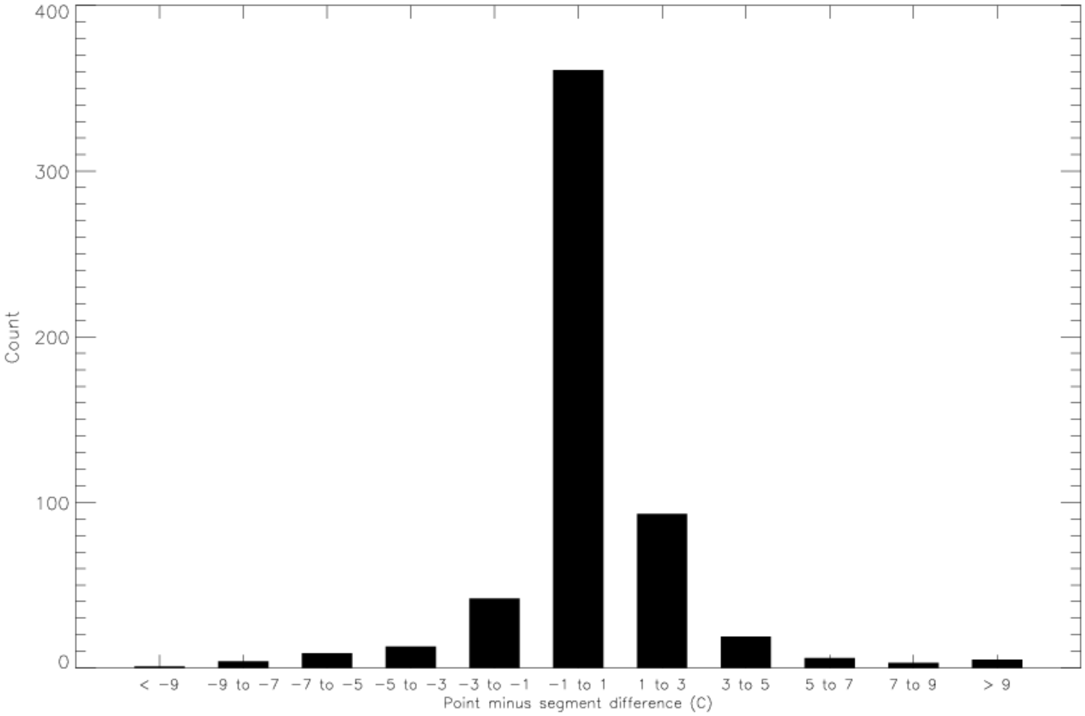


Figure 48. Nevada external air temperature differences, point vs. segment mean (Image courtesy of NCAR).

Surface temperature

The external surface temperature data show broad similarity to the other findings above (Figure 49). The correlation between the point and segment-based mean is 0.95, with a mean difference of 0.50°C and a mean absolute difference of 1.85°C. In over half of the cases (58%), the point and segment data are the same (Figure 50). For 22% of the time, the point observation is higher than its corresponding mean, and 20% of the time, the point observation is lower than the segment-based mean.

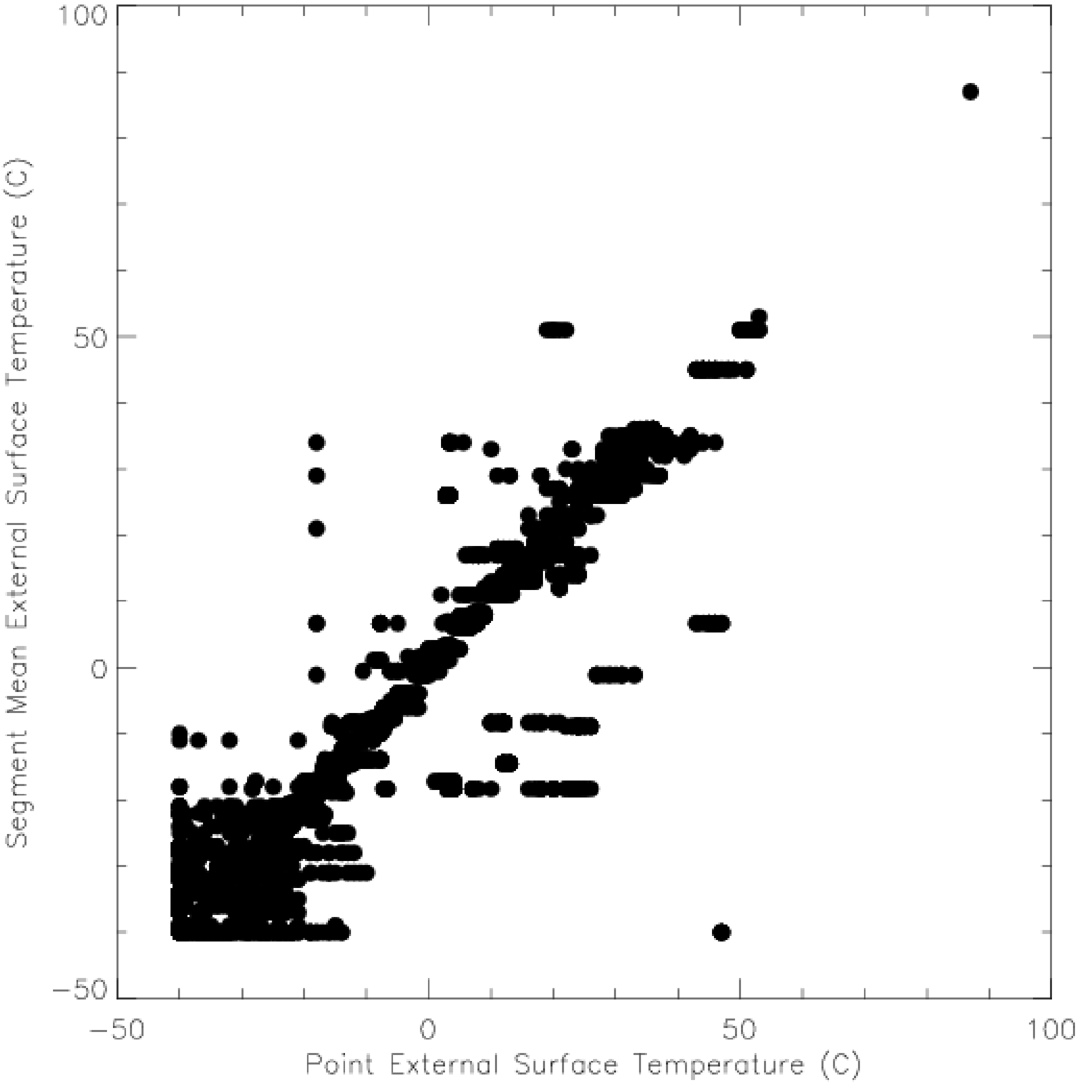


Figure 49. Nevada external surface temperature, point vs. segment mean (Image courtesy of NCAR).

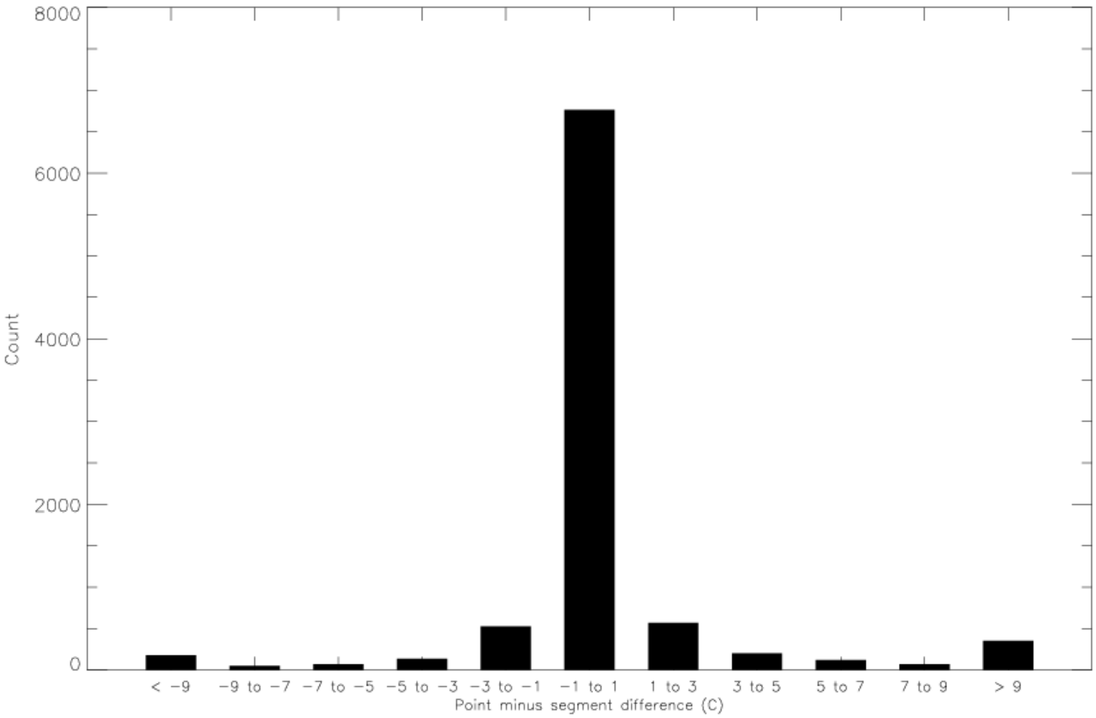


Figure 50. Nevada external surface temperature, point vs. segment mean (Image courtesy of NCAR).

Latency

A thorough understanding of latency issues will require the in-depth analysis that the University of Nevada has recently begun. This is because the Nevada data were sent as “snapshots” of data every five minutes and also subsequently supplemented with observations via flash drive uploaded later. However, we cannot discern whether all of the snapshots arrived as they were intended, nor can we easily separate a late snapshot from an archived data point. In order to get an initial viewpoint however, this analysis examined the number of observations that were outside of their initial five-minute window but less than one hour old. These are likely a combination of late observations and some early archival uploads. Overall, latency varies substantially (Figure 51), from near zero percent of the observations, such as on May 25, to over 20% late observations, such as on April 28, June 6, and June 14.

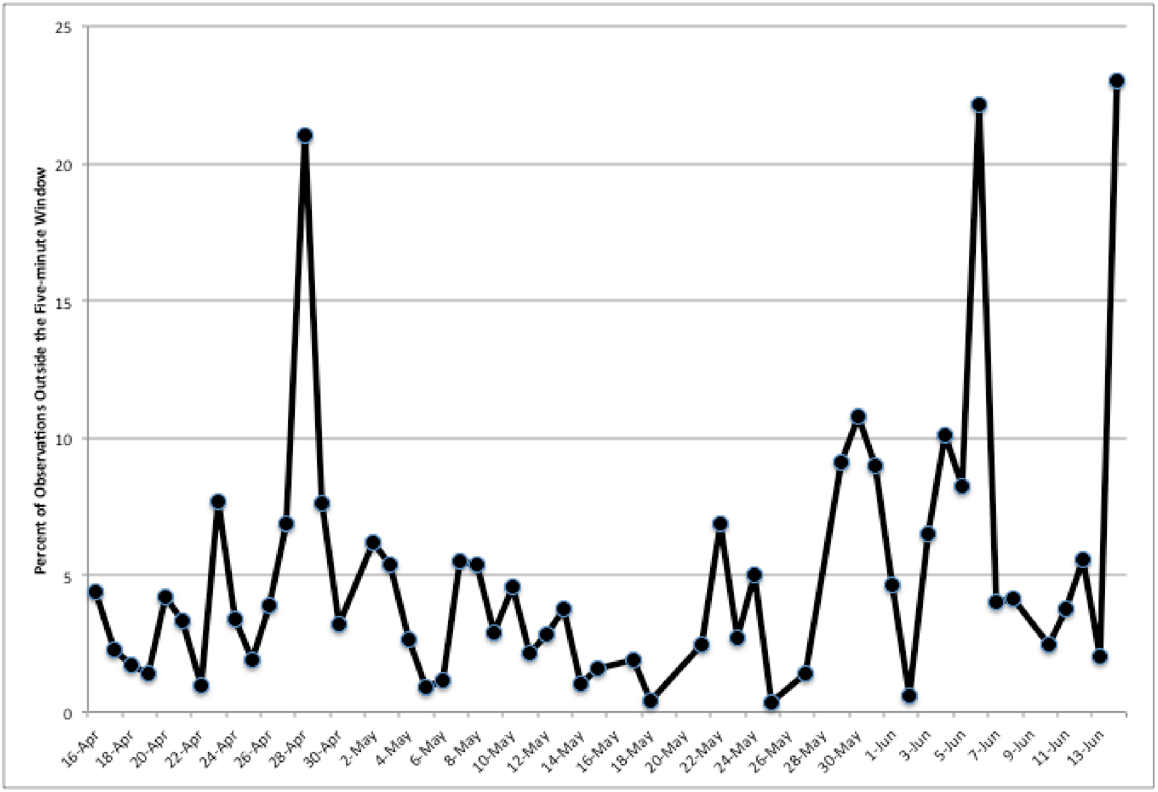


Figure 51. Percent of latent observations per day (Image courtesy of NCAR).

NCAR Results

Refer to NCAR (2012) for analyses of vehicle CANbus air temperature compared with the external sensors and DSC111 grip compared with surface temperature observations and pavement conditions.

External Sensors

Air temperatures measured by the external sensors, as well as reported by the CANbus, were compared in NCAR (2012). Overall, the external instruments and vehicle CANbus temperature measurements were relatively close. The vehicle tended to report slightly cooler temperatures compared to the other instruments. Of the external instruments, the RoadWatch tended to be the coolest while the Surface Patrol HD was the warmest, but all the instruments were within 1 – 2°C of each other and correlated well.

Only the Surface Patrol HD and RoadWatch sensors measured surface temperature. Time series for each case day are shown in Figure 52. The most obvious difference between the two sensors is the lack of reporting below 0°C by the Surface Patrol HD. Additionally, such as seen for the 8 October case, the Surface Patrol HD would sometimes report much warmer temperatures when the RoadWatch was reporting temperatures below 0°C, rather than simply being reported as missing values as happened for nearly all observations on 22 December. These differences are summarized in the boxplots in Figure 53.

The surface temperatures were compared with the pavement condition observed for the three cases for which the video camera was available for verification: 8 October, 19 November, and 1 December. For those Surface Patrol HD surface temperatures that were missing and a pavement condition was observed, 93% of the missing observations were recorded when there was snow or slush on the pavement, with the remaining 7% occurring with wet conditions. For non-missing observations, only 19% occurred with snow or slush on the pavement. It is possible that neither subfreezing temperatures nor snow-covered pavement are handled well by the Surface Patrol HD.

A statistical comparison (Table 25) between the Surface Patrol HD and the Road Watch sensors reflects the below freezing issue in the Surface Patrol sensor. For the first three cases, the two sensors are fairly closely correlated and within a few degrees of each other. For the last two, colder cases, the measurements are several degrees apart and not correlated.

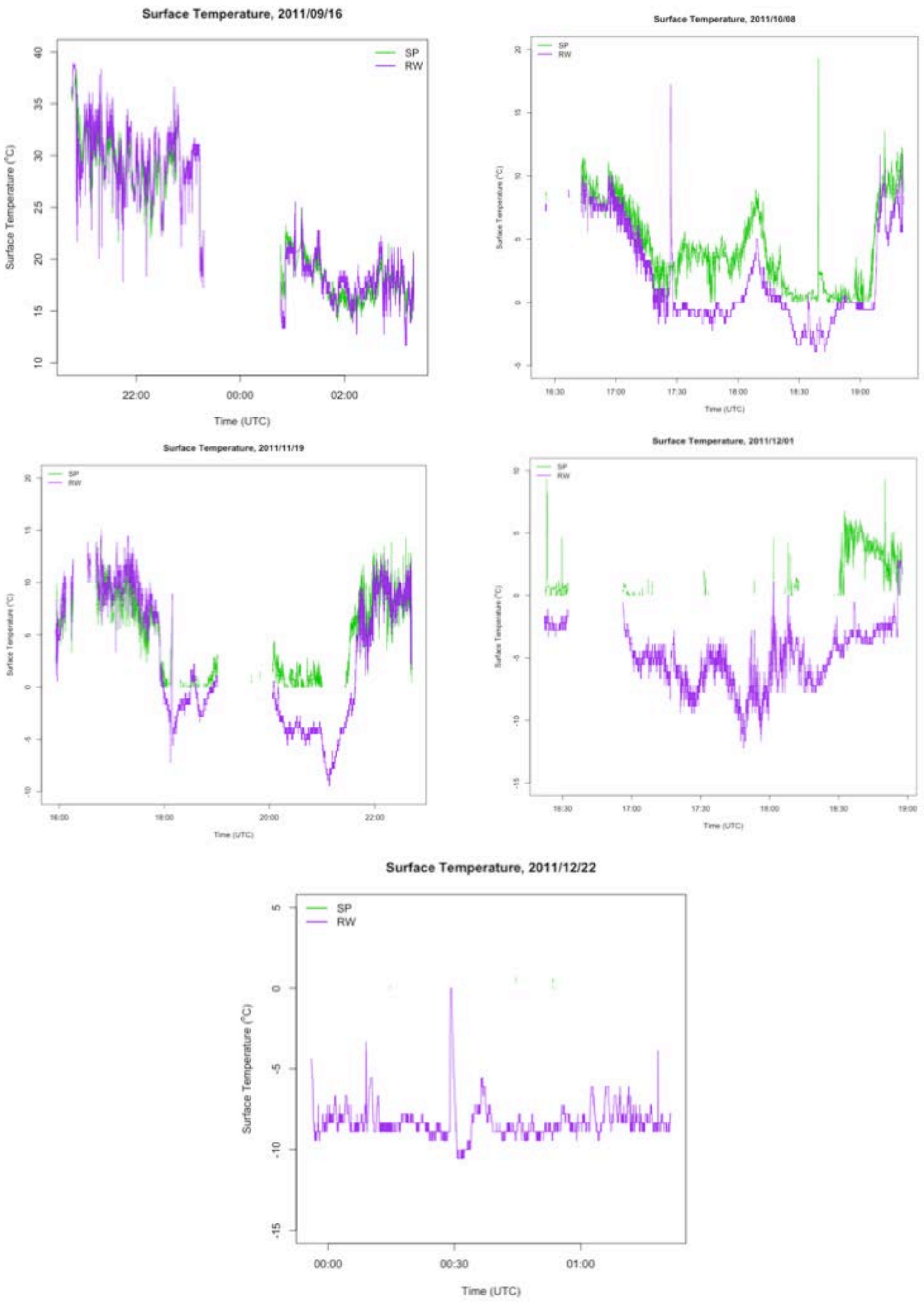


Figure 52. Time series of surface temperature from the Surface Patrol HD (green) and RoadWatch (purple) for each case (Image courtesy of NCAR).

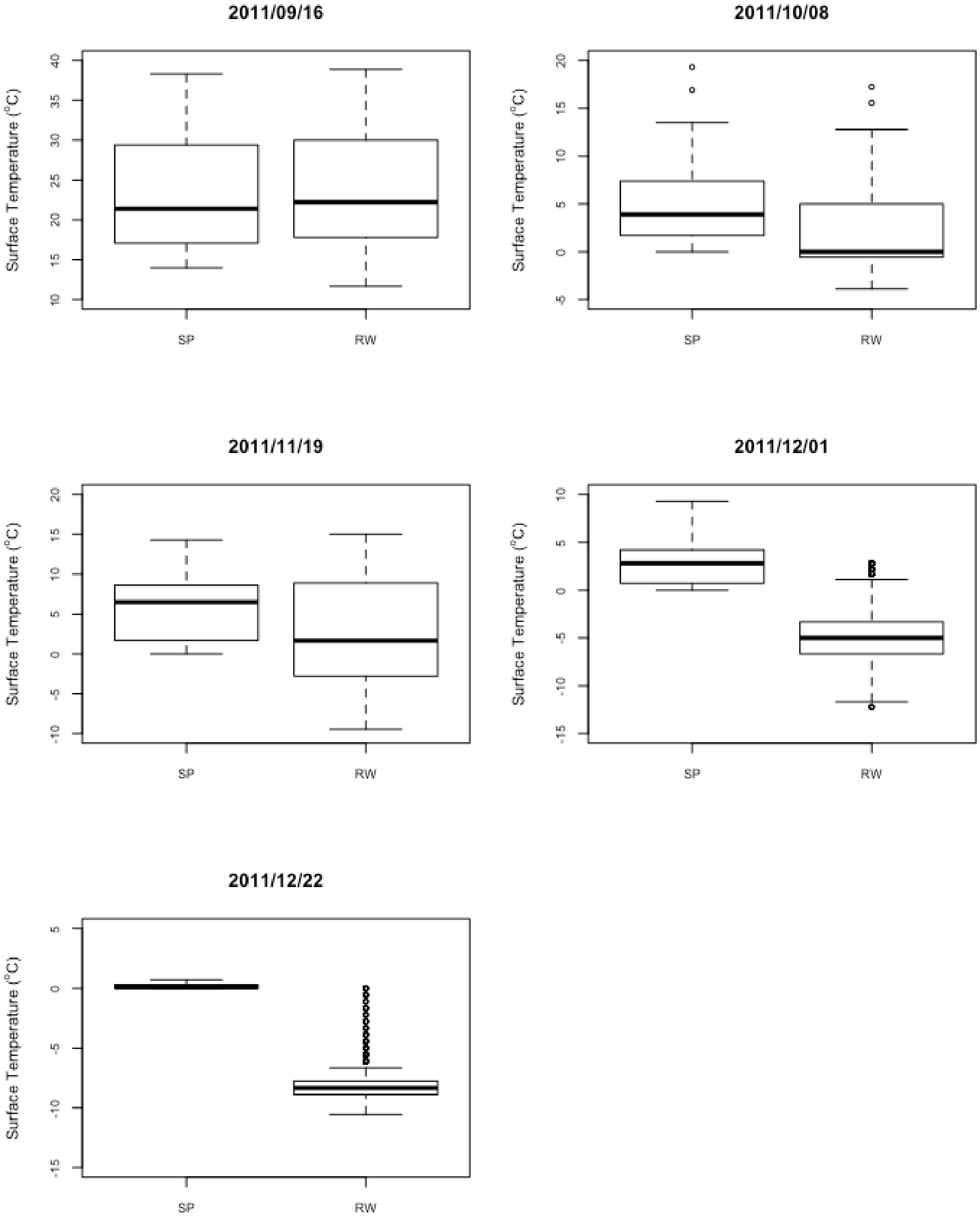


Figure 53. Boxplot of surface temperature from the Surface Patrol HD (SP) and RoadWatch (RW) for each case (Image courtesy of NCAR).

Table 25. Statistical comparison of Surface Patrol HD with RoadWatch surface temperature, non-missing pairs (Table courtesy of NCAR).

	Mean Difference	Mean Absolute Difference	Correlation
16 Sept 2011	-0.38	1.14	0.98
8 Oct 2011	2.50	2.55	0.89
19 Nov 2011	0.84	2.14	0.92
1 Dec 2011	5.32	5.35	-0.01
22 Dec 2011	9.02	9.02	0.11

Verification of CANbus and external sensors against surface station

Air temperature statistics are found in Table 26. Overall, all the instruments matched fairly well with the RWIS stations. As seen in NCAR (2012), the CANbus tended to be cooler than both the RWIS station and the external instruments, which was also true of Ford vehicles during DTE10 (Anderson et al. 2012). All the instruments tended to be within 1 – 2°C of the RWIS station observation. The largest discrepancy appears in the correlation values for 1 December, where there is either little correlation (CANbus) or negative correlation (external instruments). This could be due to the fact that there was only one RWIS station along the 1 December route, and therefore the correlation did not have enough RWIS station observations to be meaningful in this context.

Surface temperature was measured by the Surface Patrol HD and RoadWatch sensors and is found in Table 27. It should be kept in mind that for values under 0°C, the Surface Patrol HD did not report values, so for this instrument the statistics are only valid over 0°C. For this reason, to compare the two instruments, a second set of RoadWatch statistics were run using only values above 0°C. The statistics varied, but overall for reported surface temperature above 0°C, the external vehicle instruments tended to be within 1 – 2°C of the reported RWIS station observation. The statistics were also similar between the instruments. However, when considering the RoadWatch observations reported below 0°C, there were much larger differences between the mobile observation and the RWIS station observation, particular for the 1 December case, which featured cold temperatures and very snowy pavement conditions. As with air temperature, correlations may not be valid due to the few RWIS stations available.

The Airmar and Surface Patrol HD both reported dewpoint temperature, and a statistical comparison between these and the RWIS stations is found in Table 28. The Airmar tended to have a negative bias in terms of dewpoint while the Surface Patrol had a slight positive bias, but overall dewpoint temperatures tended to be within 1 – 3°C of the RWIS station observations. As with the other observations, correlation issues may be due to the limited amount of close RWIS data available.

Overall, the external instruments appear comparable to each other and the RWIS station, and the CANbus air temperatures are reasonable as well. The biggest issue occurs with surface temperatures below 0°C and snow-covered pavements, where the Surface Patrol HD does not report a surface temperature and the RoadWatch tended to have larger discrepancies with the RWIS station.

Table 26 Statistical verification of air temperature observations (°C) from sensors on the vehicle with nearby RWIS stations. Correlations were not possible for the 8 October case because only one RWIS station observation fit the spatial and temporal criteria (Table courtesy of NCAR).

Bias	CANbus	Airmar	Surface Patrol	RoadWatch
8 Oct 2011	-2.44	0.84	1.45	0.54
19 Nov 2011	-1.06	-0.22	0.91	0.75
1 Dec 2011	-1.61	-1.27	0.56	0.07
Mean Absolute Error	CANbus	Airmar	Surface Patrol	RoadWatch
8 Oct 2011	2.44	0.84	1.45	0.54
19 Nov 2011	1.31	0.93	1.15	1.09
1 Dec 2011	1.61	1.28	0.58	0.18
Correlation	CANbus	Airmar	Surface Patrol	RoadWatch
8 Oct 2011	n/a	n/a	n/a	n/a
19 Nov 2011	0.88	0.93	0.94	0.94
1 Dec 2011	0.44	-0.78	-0.70	-0.70

Table 27. Same as Table 26, but for surface temperature. No correlation was possible for the Surface Patrol for 1 December because only 1 RWIS station observation fit the spatial and temporal criteria for non-missing Surface Patrol observations (Table courtesy of NCAR).

Bias	Surface Patrol	RoadWatch > 0°C	RoadWatch
8 Oct 2011	0.10	-0.63	-2.74
19 Nov 2011	-2.02	-2.17	-2.33
1 Dec 2011	1.41	0.81	-7.13
Mean Absolute Error	Surface Patrol	RoadWatch > 0°C	RoadWatch
8 Oct 2011	0.52	0.63	2.74
19 Nov 2011	2.76	2.59	2.63
1 Dec 2011	1.41	0.81	7.14
Correlation	Surface Patrol	RoadWatch > 0°C	RoadWatch
8 Oct 2011	0.21	0.22	-0.36
19 Nov 2011	0.87	0.82	0.93
1 Dec 2011	n/a	n/a	-0.47

Table 28. Same as Table 26, but for dewpoint temperature. No correlation was possible for the 8 October case because only 1 RWIS station observation fit the spatial and temporal criteria (Table courtesy of NCAR).

Bias	Airmar	Surface Patrol
8 Oct 2011	-1.46	1.68
19 Nov 2011	-1.17	2.62
1 Dec 2011	-3.77	0.06
Mean Absolute Error	Airmar	Surface Patrol
8 Oct 2011	1.68	1.68
19 Nov 2011	3.21	2.91
1 Dec 2011	3.77	0.35
Correlation	Airmar	Surface Patrol
8 Oct 2011	n/a	n/a
19 Nov 2011	0.61	0.59
1 Dec 2011	-0.79	-0.82

VDT Algorithm Testing

First, the vehicle observations were compared with various weather conditions to determine if patterns similar to those observed during DTE10 were present (NCAR 2010). Such patterns were used for developing the Stage III algorithms, so these tests determined if the same concepts generally held true during DOCS.

When considering pavement conditions, snow versus no snow is a major concern for motorists. The speed ratio, or the ratio between the vehicle speed and road speed limit, is shown in Figure 54. Speed ratios for pavements with some snow or slush on them were considerably lower than for pavements clear of snow or slush: median 0.78 compared to median 1.0. Traction control was also reported by the vehicle, but there were relatively few instances of engagement and it was never engaged during times when the video camera was recording. During DTE10, larger interquartile ranges for acceleration, yaw, and steering angle were associated with instances of ABS, stability control, and traction control activation (NCAR 2010). This was also tested with the DOCS data, using the one available vehicle and stratifying by whether there was snow or slush on the pavement or not (Figure 55). Unlike with DTE10, for the acceleration and steering angle the snow-covered (and presumably slick) pavement condition did not show a higher interquartile range (IQR), and in fact the steering angle IQR was larger when no snow was present. The yaw did have a higher IQR for snowy pavement than pavement without snow.

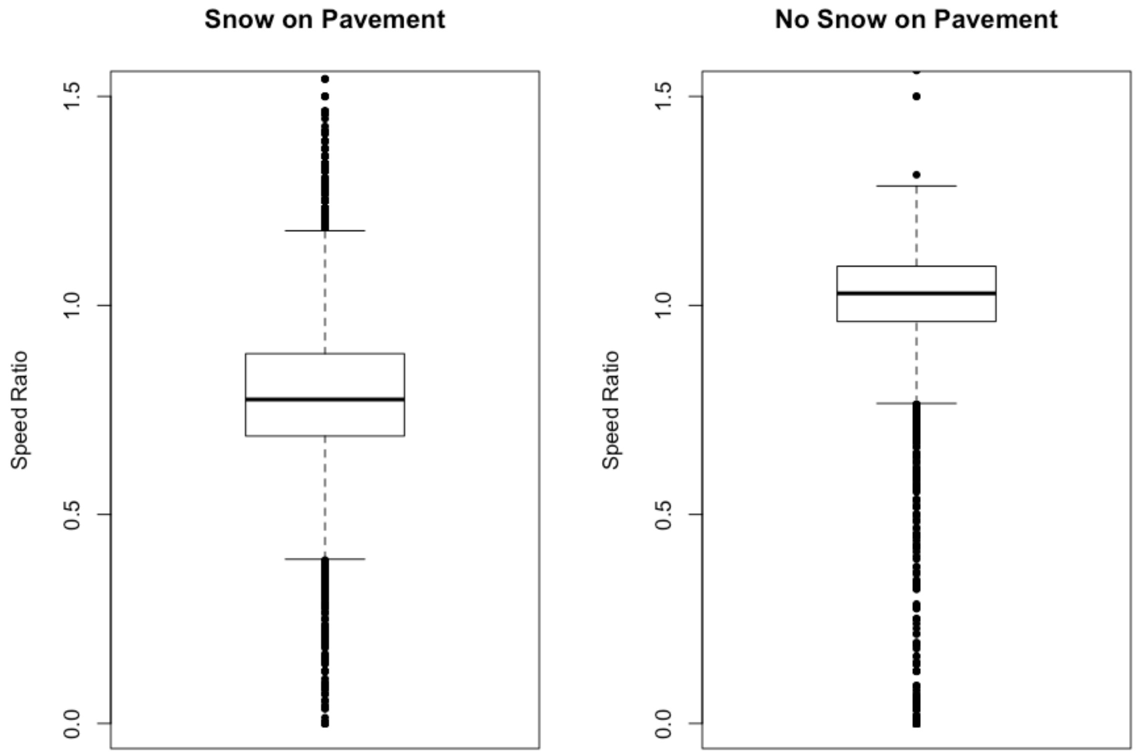


Figure 54. Boxplots of speed ratio for pavement conditions with snow (left) and without snow (right) (Image courtesy of NCAR).

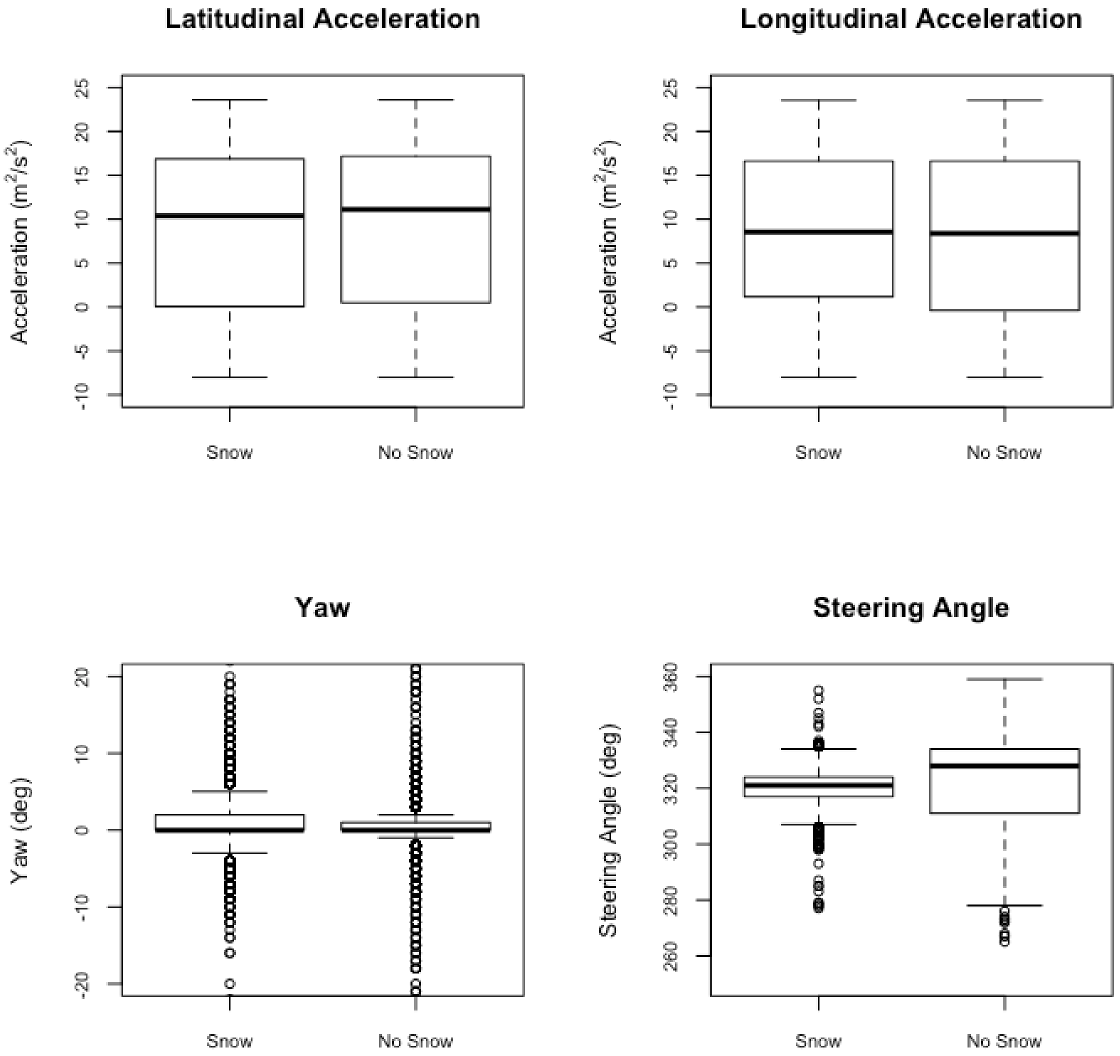


Figure 55. Boxplots of select vehicle CANbus observations stratified by pavement with and without snow. The y-axes for yaw and steering angle exclude some outliers (Image courtesy of NCAR).

Second, the DOCS observations were run through the VDT 3.0 Stage III algorithms and the output compared with the verification determined from the video camera. The results of this process are presented for each of the three Stage III algorithms.

Precipitation

Results for precipitation are shown in Table 1. The "heavy" designation was subjectively assigned based on the video verification. None of the dry, or no precipitation, observation times were misclassified. However, several of the rain and frozen precipitation observations were misclassified, mostly with the precipitation being classified as not occurring, or dry.

The rain observations misclassified as frozen occurred over a 3-minute period on 8 October, when the vehicle was driven through the rain/snow line along the foothills west of Boulder. The frozen classification was due to an air temperature of 0, which in the algorithm's logic leads to a frozen distinction over liquid. Future algorithm development will reconsider this logic along with the radar reflectivity categories. The rain observations misclassified as dry occurred over a six-minute period on 19 November. On the video, raindrops were very small and infrequent, and the dry designation does not seem unreasonable.

About 64% of the frozen precipitation observed was misclassified as dry. This occurred on each of the three case days. Over a non-contiguous period on 8 October, off wipers and high speed ratios led to the dry classification. With the high reflectivity during this time (20.5 to 23.5 dBZ), this section of the logic will need to be further examined. The observations during the non-contiguous 45-minute period on 19 November spanned both the frozen and mixed branches. For the frozen branch, low radar reflectivities, off wipers, and high speed ratios all contributed to the misclassification. Future work will consider how these classifications are made, particularly with very light reflectivity returns. For the mixed branch, no radar return and off wipers led to the dry category, along with high speed ratios. Beam blockage in the mountains may cause issues with using radar reflectivity, so other observations will need to be considered. This is likely the case for 1 December, where over a non-contiguous 50-min period low reflectivity automatically led to a dry classification. Additional observations will be considered for these low or no radar reflectivity cases.

Several heavy frozen observations were also misclassified as dry. This was due to the lack of radar reflectivity, which may be due to beam blockage in the mountains. They all occurred on 19 November. Ways to determine precipitation in the absence of radar data will be explored with future datasets, including the use of satellite cloud classifications. A few heavy frozen observations were also misclassified as light intensity, one observation on 19 November and the rest over a non-contiguous 14-minute period on 1 December. Speed ratios and wiper status for higher reflectivities played a role in the light designation, but there was still the issue of missing or reduced radar reflectivities.

Table 29. Comparison of precipitation observed on the video camera with output from the VDT precipitation algorithm (Table courtesy of NCAR).

	Observed					
Forecast		Dry	Rain	Heavy Rain	Frozen	Heavy Frozen
	Dry	31	7	0	81	24
	Rain	0	2	0	0	0
	Heavy Rain	0	0	0	0	0
	Frozen	0	3	0	45	8
	Heavy Frozen	0	0	0	0	8

Pavement

The pavement algorithm was particularly hard to verify for two reasons. First, multiple pavement conditions often exist on the same surface, for example, a road surface is partially wet and partially snow-covered and road splash is occurring. Second, the road conditions observed on the camera varied from the designations of the algorithm. This was particularly an issue for slick pavement, which could not be observed, and slushy pavement, which was a mix of wet and snowy conditions. For these reasons, two comparisons were made: one using the possible algorithm outputs and one using the most accurate description of the observed road conditions.

The first comparison (Table 30) was made by determining the pavement condition observed on the video camera using a predetermined list of possible outputs from the pavement condition algorithm. This allows for a straightforward comparison, but is less accurate than comparing to the actual observed conditions, particularly because slickness could not be observed on the camera. If a road segment had the algorithm-outputted condition existing on it, it was counted as correct. For example, if the pavement was observed to be both wet and snowy with road splash occurring, then the algorithm output of wet, snow, or splash could be counted as correct. Slushy pavement was counted as snow. In cases where the algorithm missed, this miss was counted in the snow column if slushy or snowy pavement was observed as one of the multiple conditions because this was the most hazardous condition and thus “worse” to miss. For example, if the algorithm outputted “dry” and the observed conditions were wet and snowy, this was marked in the table in the snow column for observed and dry row for forecast. Road splash was never considered for the misses column because it always occurred in conjunction with another condition, as the splash itself is not an independent pavement condition.

If snowy pavement is assumed to be slick, then the algorithm did a comparable job to what was found for DTE10 data, with 58% of observations being correctly classified. There was still some clear over alerting by the slickness algorithm. The 12 dry observations classed as slick all took place on 19 November at various points. All video of these segments showed the vehicle making “S” curves, curving first one direction and then the other. It is likely that the different IQRs used in the slick algorithm are overly sensitive to this type of movement. The same was true with the wet segments misclassified as slick. This would likely be a common problem in the mountains, where many roads weave through canyons.

The other major issue was with wet and snowy pavements being misclassified as dry. For the wet segments, all occurred on 19 November. For some of these segments, the pavement had just transitioned from dry to becoming damp. For several others, the algorithm was clearly wrong, and pavements were wet with road splash. For these segments, low radar reflectivities and cool temperatures likely led to the dry classification. These variables will be kept in mind as more datasets are analyzed to tune the algorithms. For the snowy pavements, higher speed ratios and low reflectivity contributed to the misclassifications.

The second comparison (Table 31) stratified the algorithm output by the exact conditions observed on the video camera, including several instances where more than one pavement condition existed on the roadway. As noted in the analysis of Table 30, the major issues were dry conditions being assigned for several wet and snowy pavements, and the slick algorithm tending to over alert.

Table 30. Comparison of observed pavement conditions with output from the pavement condition algorithm where the observed pavement conditions were determined from the list of possible outputs from the algorithm (Table courtesy of NCAR).

	Observed					
Forecast		Dry	Wet	Splash	Snow	Slick
	Dry	69	55	0	32	0
	Wet	2	17	0	7	0
	Splash	0	0	3	5	0
	Snow	0	0	0	1	0
	Slick	12	33	0	109	0

Table 31 Comparison of observed pavement conditions with output from the pavement condition algorithm where the observed pavement conditions were not based on possible output from the algorithm (Table courtesy of NCAR).

	Observed									
Forecast		Dry	Wet	Wet/ Slush	Wet/ Splash	Wet/ Snow	Wet/ Slush/ Splash	Wet/ Snow/ Splash	Snow	Snow/ Slush/ Splash
	Dry	69	24	3	31	6	11	12	10	2
	Wet	2	10	5	0	1	1	0	7	0
	Splash	0	0	0	0	0	3	0	5	0
	Snow	0	0	0	0	0	1	0	0	0
	Slick	12	20	12	13	16	10	5	69	2

Visibility

Results for visibility are shown in Table 32. The normal and low visibilities were subjectively assigned based on the video verification. Blowing snow and heavy rain were not observed, nor were they assigned by the algorithm.

Nearly all the observations were classified as normal visibility by the algorithm. The fuzzy logic equations were examined individually to determine which observations that occurred during low visibility observations contributed to increased interest (a low visibility designation occurs when interest is greater than 0.5).

The low air temperature of -11 – 0°C contributed little to the interest. The many “off” wiper designations also did not contribute. The remaining were intermittent and would only have contributed slightly. Speed ratios were 0.46 and greater, and the ratios on the lower end of this range would have contributed positively. The headlight status only included low beams, and no fog lights, and the low contribution may indicate that there is too much emphasis on headlight status in the current algorithm, particularly fog lights. The nearest surface station visibilities were quite low (under 2 miles) and thus would have contributed positively. High relative humidities of 60% to 94% would have contributed positively as well.

Overall, there are indications that certain aspects of the visibility algorithm, which was derived from DTE09 and DTE10 observations, may not be optimally tuned for a variety of regions and terrains. In particular, for the DOCS cases there was too much emphasis on fog light status, air temperature, and wiper status to allow the 0.5 interest threshold to be reached for the low visibility cases. These results will be taken into account as future datasets are mined for the purpose of improving the algorithm.

Table 32. Comparison of visibility observed on the video camera with output from the VDT visibility algorithm (Table courtesy of NCAR).

	Observed				
		Normal	Low	Blowing Snow	Heavy Rain
Forecast	Normal	175	182	0	0
	Low	2	1	0	0
	Blowing Snow	0	0	0	0
	Heavy Rain	0	0	0	0

Chapter 5 Discussion

This report discussed the data collection efforts undertaken by NDOT, MNDOT, and NCAR to achieve the goals of the IMO study during 2011 and 2012, including analyses of both the amount and type of data collected as well as the quality of these data. Additionally, the data were used to help determine the usefulness of such data in pavement temperature forecasts and to inform the continued enhancement of the VDT Stage III algorithms. The following are the major points and conclusions from these analyses:

- The three external sensors used in the IMO (RoadWatch, Surface Patrol HD, and Airmar) were, overall, closely-matched and well-correlated with the nearby RWIS stations at all three IMO data collection regions. There were two exceptions to this with the Surface Patrol HD, which tended to have periods of noisiness within its observations as well as issues dealing with snow covered pavement during DOCS.
- A summary of MNDOT CANbus quality will be added once the analysis is complete.
- The NDOT CANbus data is not currently of a very high quality, although the barometric pressure may be reasonable. A major issue is the missing observations. Additionally, intake air temperature is not representative of the ambient air temperature around the vehicle and hence cannot be used as such. The barometric pressure quality was difficult to analyze given the complexity of terrain and the coarse 10-hPa resolution.
- The DOCS CANbus air temperature data was closely correlated with the nearest RWIS stations, matching the data quality expectations presented in Anderson et al. (2012).
- The observations analyzed along VDT segments show overall close similarity with the individual observation points along these segments, leading to the conclusion that VDT segments are generally representative of what is being observed. One possible exception is air temperature, which, although highly correlated between segment and point, does not capture variations along the segment with the mean value. The standard deviation-related statistics also provided by the VDT would likely be useful representations of such variations.
- Add MNDOT latency here. Although final conclusions on NDOT data latency will have to wait until the University of Nevada completes their analysis, early indications are that latency varies substantially based on day, from a low of 0% to a high of about 20%.
- Overall, there is a consistently strong correspondence between the VDT analysis of surface temperature and what is being observed at RWIS stations. Although this correspondence cannot prove irrefutably that the VDT output would have significant value if used to forecast pavement temperatures away from RWIS sites, it is a promising result.
- Data from DOCS was run through the VDT Stage III algorithms and the results compared with the video camera verification. Although no actual changes can be

made to the algorithms based on the observations of a single vehicle over three days, the results of this analysis have provided guidance for algorithm development as it moves forward with additional and larger datasets.

- There were substantial percentages of missing, improperly formatted, and invalid data received in the MNDOT and NDOT datasets, creating difficulties for the analysis.

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Drobot, S., A. Anderson, M. Chapman, C. Johansen, 2009: Vehicle Standards. NCAR Tech. Rep., 15 pp.

NCAR, 2010: Task 11: VDT Enhancements, 47 pp.

NCAR, 2012: Task 9: Summary of the Demonstration of CANbus Study.

Appendix A

Tables describing each PGN group, the included SPNs, and range of values reported are included here.

PGN 61441

Electronic brake controller 1

SPN #	Description	Values
561	ASR engine control active	0, 2
562	ASR brake control active	0, 1
563	ABS active	0, 1, 2
1121	EBS brake switch	0, 2
521	Brake pedal position	0, 1.2, 3.75, 6.8, 7, 50.0, 76.8, 100, 102.0, 102.7, 275.5
575	ABS off-road switch	0, 1, 2
576	ASR off-road switch	0, 1, 245
577	ASR hill-holder switch	0, 1
1238	Traction control override switch	0, 2
972	Accelerator interlock switch	0, 1, 2
971	Engine derate switch	0, 1, 2
970	Engine auxiliary shutdown switch	0, 1, 2
969	Remote accelerator enable switch	0, 1, 2
973	Engine retarder selection	0, 1.6, 2.4, 8.4, 40.8, 76.8, 81.6, 99.2, 99.7, 100, 102, 102.002, 102.020, 102.092, 1022
1243	ABS fully operational	0, 1, 1.816, 2
1439	EBS red warning signal	0, 1, 2
1438	ABS/EBS amber warning signal (powered vehicle)	0, 1, 2, 1287.75
1793	ATC/ASR information signal	0, 1, 2
1481	Source address of controlling device for brake control	0, 2, 6, 17, 20, 102, 192, 240, 254, 255, 2515
2911	Halt brake switch	0, 1, 2
1836	Trailer ABS status	0, 1, 2
1792	Tractor-mounted trailer ABS warning signal	0, 1, 2

PGN 61442

Electronic transmission controller 1

SPN #	Description	Values
560	Transmission driveline engaged	0, 0.875, 1, 1.875, 2, 5, 9, 11, 75, 102, 124, 160, 222.5, 1205
573	Transmission torque converter lockup engaged	0, 0.75, 0.875, 1, 1.875, 2, 2.25, 5, 5.996, 10.75, 11.875, 15, 55, 102, 124, 169, 211, 700.25
574	Transmission shift in process	0, 0.875, 1, 1.875, 2, 3, 4, 5, 8, 15, 28, 32.875, 40, 75, 88, 99, 102, 129, 136, 142, 1016
4816	Transmission torque converter lockup transition in process	0, 1, 2, 9, 128
191	Transmission output shaft speed	0 to 80100, median 0 mean 578.4
522	Percent clutch slip	0 to 10260, median 102 mean 101.6
606	Engine momentary overspeed enable	0, 1, 2, 8.125, 128
607	Progressive shift disable	0, 1, 2, 5, 10, 11, 12, 15, 102, 129, 140.75, 151.266, 1127, 11224.75, 28187.375
5015	Momentary engine maximum power enable	0, 1, 2
161	Transmission input shaft speed	0 to 65650, median 703 mean 825.1

PGN 61443

Electronic engine controller 2

SPN #	Description	Values
558	Accelerator pedal 1 low idle switch	0, 1, 1.875, 2
559	Accelerator pedal kickdown switch	0, 0.375, 1, 124
1437	Road speed limit status	0, 1, 15, 75, 181, 1125, 1132
2970	Accelerator pedal 2 low idle switch	0
91	Accelerator pedal position	0 to 9607, median 0, mean 16.09
92	Engine percent load at current speed	0 to 2468, median 14, mean 26.81
974	Remote accelerator pedal position	0, 0.8, 1, 2.4, 6.8, 10, 10.375, 16.4, 40.8, 76.8, 96, 102, 102.01, 102.05, 102.088, 102.5, 103, 105
29	Accelerator pedal position 2	0, 0.8, 2.4, 40.8, 54, 76.8, 97.6, 101, 102, 102.1, 102.645, 1020, 10281
2979	Vehicle acceleration rate limit status	0, 1, 2
5021	Momentary engine maximum power enable feedback	0, 2
5399	DPF thermal management active	0, 1, 2
5400	SCR thermal management active	0, 1, 2
3357	Actual maximum available engine percent torque	0 to 102.2, median 102 mean

SPN #	Description	Values
		87.83
5398	Estimated pumping percent torque	-1 to 2540, median 254 mean 241.4

PGN 61444

Electronic engine controller 1

SPN #	Description	Values
899	Engine torque mode	0, 1, 1.875, 2, 4, 5, 6, 7, 8, 9, 11, 13, 14, 15, 24, 62, 80, 102, 875
4154	Actual engine percent torque high resolution	0 to 1875, median 1.875 mean 1.639
512	Drivers demand engine percent torque	-127 to 15660, median 124 mean 136.5
513	Actual engine percent torque	-1 to 19490, median 130 mean 129.2
190	Engine speed	0 to 94380, median 786.6 mean 918
1483	Source address of controlling device for engine control	0, 1, 2, 3, 4, 6, 11, 15, 17, 32, 40, 55.25, 65.25, 102, 127, 135, 192, 216, 240, 255, 256, 327.25, 677, 695, 769.25, 1238, 1350, 25769
1675	Engine starter mode	0, 1, 1.75, 2, 4, 5, 6, 8, 12, 13, 14, 15, 29, 82.8, 139.25, 150, 155, 647.75, 1515, 11454, 25481.5
2432	Engine demand percent torque	-54 to 135, median 212 mean 192.9

PGN 61445

Electronic transmission controller 2

SPN #	Description	Values
524	Transmission selected gear	-1, 0, 1.875, 5, 12.75, 16, 123, 124, 125, 126, 127, 128, 129, 129.75, 130, 131, 132, 133, 134, 191, 254, 2047.969, 12412
526	Transmission actual gear ratio	0 to 1268, median 0.671 mean 1.045
523	Transmission current gear	-1, 1, 5, 31, 77, 120, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, 133, 134, 201, 203, 239, 254, 1240, 1241, 1305
162	Transmission requested range	-1, 0, 1, 1.25, 5, 31, 77, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, 133, 134, 201, 203, 239, 254, 1272
163	Transmission current range	n/a

PGN 61469

Steering angle sensor info

SPN #	Description	Values
3683	Steering wheel angle	n/a
3684	Steering wheel angle range counter	n/a
3685	Steering wheel angle range counter type	n/a
3686	Steering wheel angle range	n/a
3687	Steering angle sensor active mode	n/a
3688	Steering angle sensor calibrated	n/a
3689	Message counter	n/a
3690	Message checksum	n/a

PGN 61482

Angular rate info

SPN #	Description	Values
4983	Pitch rate extended range	n/a
4984	Roll rate extended range	n/a
4985	Yaw rate extended range	n/a
4986	Pitch rate extended range figure of merit	n/a
4987	Roll rate extended range figure of merit	n/a
4988	Yaw rate extended range figure of merit	n/a
4989	Angular rate measurement latency	n/a

PGN 61485

Acceleration sensor

SPN #	Description	Values
5347	Lateral acceleration extended range	n/a
5348	Longitudinal acceleration extended range	n/a
5349	Vertical acceleration extended range	n/a
5350	Lateral acceleration extended range figure of merit	n/a
5351	Longitudinal acceleration extended range figure of merit	n/a
5352	Vertical acceleration extended range figure of merit	n/a
5353	Support variable transmission repetition rate for acceleration sensor	n/a

PGN 64773

Direct lamp control data 1

SPN #	Description	Values
5093	Engine protect lamp	n/a
5094	Engine amber warning lamp	n/a
5095	Engine red stop lamp	n/a

SPN #	Description	Values
5096	OBD malfunction indicator lamp	n/a
5097	Engine brake active lamp	n/a
5098	Compression brake enable switch lamp	n/a
5099	Engine oil pressure low lamp	n/a
5100	Engine coolant temp high lamp	n/a
5101	Engine coolant level low lamp	n/a
5102	Engine idle management idle active lamp	n/a
5103	Engine air filter restriction lamp	n/a
5470	Engine fuel filter restricted lamp	n/a
5416	Engine wait to start lamp	n/a

PGN 64776

Engine oil message

SPN #	Description	Values
5055	Engine oil viscosity	n/a
5056	Engine oil density	n/a
5468	Engine oil relative dielectricity (hi res)	n/a

PGN 64777

High resolution fuel consumption (liquid)

SPN #	Description	Values
5053	Hi res engine trip fuel	n/a
5054	Hi res engine total fuel used	n/a

PGN 64851

Engine average info

SPN #	Description	Values
4151	Engine exhaust temp average	n/a
4153	Engine exhaust temp average bank 1	n/a
4152	Engine exhaust temp average bank 2	n/a

PGN 64870

Engine temperature 4

SPN #	Description	Values
4076	Engine coolant temp 2	n/a
4193	Engine coolant pump outlet temp	n/a
4194	Engine coolant thermostat opening	n/a
4288	Engine exhaust valve actuation system oil temp	n/a
5020	Engine exhaust gas recirculation 1 mixer intake temp	n/a

PGN 64972

Operators external light controls message

SPN #	Description	Values
2873	Work light switch	0, 15
2872	Main light switch	0, 15
2876	Turn signal switch	0, 1, 2, 14
2875	Hazard light switch	0
2874	High-low beam switch	0
2878	Operators desired back-light	n/a
2877	Operators desired delayed lamp off time	n/a

PGN 64973

Operator wiper and washer controls message

SPN #	Description	Values
2864	Front non-operator wiper switch	n/a
2863	Front operator wiper switch	n/a
2865	Rear wiper switch	n/a
2869	Front operator wiper delay control	n/a
2870	Front non-operator wiper delay control	n/a
2871	Rear wiper delay control	n/a
2867	Front non-operator wiper switch	n/a
2866	Front operator wiper switch	n/a
2868	Rear washer function	n/a

PGN 64992

Ambient conditions 2

SPN #	Description	Values
2610	Solar intensity percent	n/a
2611	Solar sensor maximum	n/a
4490	Specific humidity	n/a

PGN 65031

Exhaust temp

SPN #	Description	Values
65031	Engine exhaust gas temp right manifold	n/a
65031	Engine exhaust gas temp left manifold	n/a

PGN 65088

Lighting data

SPN #	Description	Values
2404	Running light	n/a
2352	Alternate beam headlight	n/a
2350	Low beam headlight	n/a
2348	High beam headlight	n/a
2388	Running light	n/a
2386	Alternate beam headlight	n/a
2370	Low beam headlight	n/a
2368	High beam headlight	n/a
2392	Backup light and alarm horn	n/a
2376	Center stop light	n/a
2374	Right stop light	n/a
2372	Left stop light	n/a
2384	Implement clearance light	n/a
2382	Tractor clearance light	n/a
2380	Implement marker light	n/a
2378	Tractor marker light	n/a
2390	Rear fog lights	n/a
2358	Tractor underside mounted work lights	n/a
2360	Tractor rear low mounted work lights	n/a
2362	Tractor rear high mounted work lights	n/a
2364	Tractor side low mounted work lights	n/a
2366	Tractor side high mounted work lights	n/a
2354	Tractor front low mounted work lights	n/a
2356	Tractor front high mounted work lights	n/a
2398	Implement OEM Option 2 light	n/a
2396	Implement OEM Option 1 light	n/a
2407	Implement right facing work light	n/a
2598	Implement left facing work light	n/a
2396	Implement right forward work light	n/a
2407	Implement left forward work light	n/a
2598	Implement rear work light	n/a

PGN 65100

Total averaged info

SPN #	Description	Values
1834	Engine total average fuel rate	n/a
1835	Engine total average fuel economy	n/a

PGN 65134

High resolution wheel speed

SPN #	Description	Values
1592	Front axle left wheel speed	n/a
1593	Front axle right wheel speed	n/a
1594	Rear axle left wheel speed	n/a

SPN #	Description	Values
1595	Rear axle right wheel speed	n/a

PGN 65171

Engine electrical system/module info

SPN #	Description	Values
1204	Electrical load	n/a
1205	Safety wire status	n/a

PGN 65191

Alternator temp

SPN #	Description	Values
1122	Engine alternator bearing 1 temp	n/a
1123	Engine alternator bearing 2 temp	n/a
1124	Engine alternator winding 1 temp	n/a
1125	Engine alternator winding 2 temp	n/a
1126	Engine alternator winding 3 temp	n/a

PGN 65215

Wheel speed info

SPN #	Description	Values
904	Front axle speed	0 to 255.1, median 0 mean 18.81
905	Relative speed front axle left wheel	-7.812 to 7.688, median 0 mean -0.2119
906	Relative speed front axle right wheel	-7.812 to 5, median 0 mean -0.2211
907	Relative speed rear axle #1 left wheel	-7.812 to 8.125, median 0 mean -0.2392
908	Relative speed rear axle #1 right wheel	-7.812 to 15, median 0 mean -0.2258
909	Relative speed rear axle #2 left wheel	-7.812, -7.438, -6.75, -1.438, 7.188, 8, 8.120, 8.125, 1778.5
910	Relative speed rear axle #2 right wheel	-7.812, -7.562, -7.438, -6.75, 4.812, 7.188, 8.125, 8.153

PGN 65217

High resolution vehicle distance

SPN #	Description	Values
917	High resolution total vehicle distance	Some 0, otherwise large #s
918	High resolution trip distance	Some 0, otherwise large #s

PGN 65237

Alternator info

SPN #	Description	Values
589	Alternator speed	n/a
3353	Alternator 1 status	n/a
3354	Alternator 2 status	n/a
3355	Alternator 3 status	n/a
3356	Alternator 4 status	n/a

PGN 65248

Vehicle distance

SPN #	Description	Values
244	Trip distance	Some 0, otherwise large #s
245	Total vehicle distance	Some 0, otherwise large #s

PGN 65253

Engine hours & revolutions

SPN #	Description	Values
247	Engine total hours of operation	23 to 203.5, median 55.95 mean 65.24
249	Engine total revolutions	Large numbers

PGN 65255

Vehicle hours

SPN #	Description	Values
246	Total vehicle hours	0 to 203.4, otherwise large numbers
248	Total power takeoff hours	0 to 9.6

PGN 65260

Vehicle identification

SPN #	Description	Values
65260	VIN	n/a

PGN 65261

Cruise control/vehicle speed setup

SPN #	Description	Values
74	Max vehicle speed limit	112
87	Cruise control high set limit speed	112
88	Cruise control low set limit speed	48

PGN 65262

Engine temperature 1

SPN #	Description	Values
110	Engine coolant temp	-1 to 143, median 113 mean 102
174	Engine fuel temp 1	-1 to 254, median 69 mean 112.6
175	Engine oil temp 1	0 to 2048, median 351 mean 496.1
176	Engine turbo oil temp	0, 2047.969, 20128
52	Engine intercooler temp	-1, 239, 253, 254
1134	Engine intercooler thermostat opening	0, 0.8, 96.4, 102

PGN 65263

Engine fluid level/pressure 1

SPN #	Description	Values
94	Engine fuel delivery pressure	0, 1020, 1021
22	Engine extended crankcase blow-by pressure	0, 5.8, 12, 12.328, 12.5, 12.75
98	Engine oil level	0, 0.12, 0.75, 1.68, 10, 10.2
100	Engine oil pressure	0 to 1020, median 296 mean 269.4
101	Engine turbo oil temp	0 to 1279, median 512, mean 446.2
109	Engine coolant pressure	0 to 510, median 510, mean 500
111	Engine coolant level	0 to 100, median 100, mean 97.96

PGN 65265

Cruise control/vehicle speed

SPN #	Description	Values
69	Two speed axle speed	0, 1, 396
70	Parking brake switch	0, 1
1633	Cruise control pause switch	0
3807	Park brake release inhibit request	0
84	Wheel-based vehicle speed	0 to 25880, median 0 mean 35.69
595	Cruise control active	0, 1, 2, 5, 102

SPN #	Description	Values
596	Cruise control enable switch	0, 1, 1.875, 2, 1166
597	Brake switch	0, 1, 2, 102
598	Clutch switch	0, 1, 2
599	Cruise control set switch	0, 1
600	Cruise control coast/decelerate switch	0, 1, 7.125, 7.969, 15, 25
601	Cruise control resume switch	0, 1
602	Cruise control accelerate switch	0, 1
86	Cruise control speed	0 to 6302, median 0 mean 38.91
976	PTO governor state	0, 1, 2
527	Cruise control states	0, 1, 2, 15
968	Engine idle increment switch	0, 1, 2
967	Engine idle decrement switch	0, 1, 2
966	Engine test mode switch	0, 1, 1265.75
1237	Engine shutdown override switch	0

PGN 65266

Fuel economy (liquid)

SPN #	Description	Values
183	Engine fuel rate	0 to 3266, median 2.6 mean 10.85
184	Engine instantaneous fuel economy	0 to 1130, median 0 mean 2.841
185	Engine instantaneous fuel economy	0 to 128, median 1.74 mean 2.476
51	Engine throttle valve 1 position	0, 1.2, 2, 2.4, 4.4, 4.8, 5.2, 5.6, 6, 6.4, 6.8, 7.2, 7.6, 8, 8.4, 8.8, 9.2, 9.6, 10, 10.4, 10.8, 11.2, 81.2, 96, 102, 147.969
3673	Engine throttle valve 2 position	0, 0.25, 0.8, 4.5, 40.8, 76.8, 100, 102, 102.5

PGN 65269

Ambient conditions

SPN #	Description	Values
108	Barometric pressure	0, 93, 93.5, 94, 94.5, 95, 95.5, 96, 96.5, 97, 97.5, 98, 98.5, 99, 99.5, 100, 100.5, 101, 101.5, 102, 127.5
170	Cab interior temp	0, 2047.969
171	Ambient air temp	0 to 2048, median 2048 mean 1377
172	Engine air intake temp	-1 to 254, median 137.7 mean 137.7
79	Road surface temp	n/a

PGN 65271

Vehicle electrical power 1

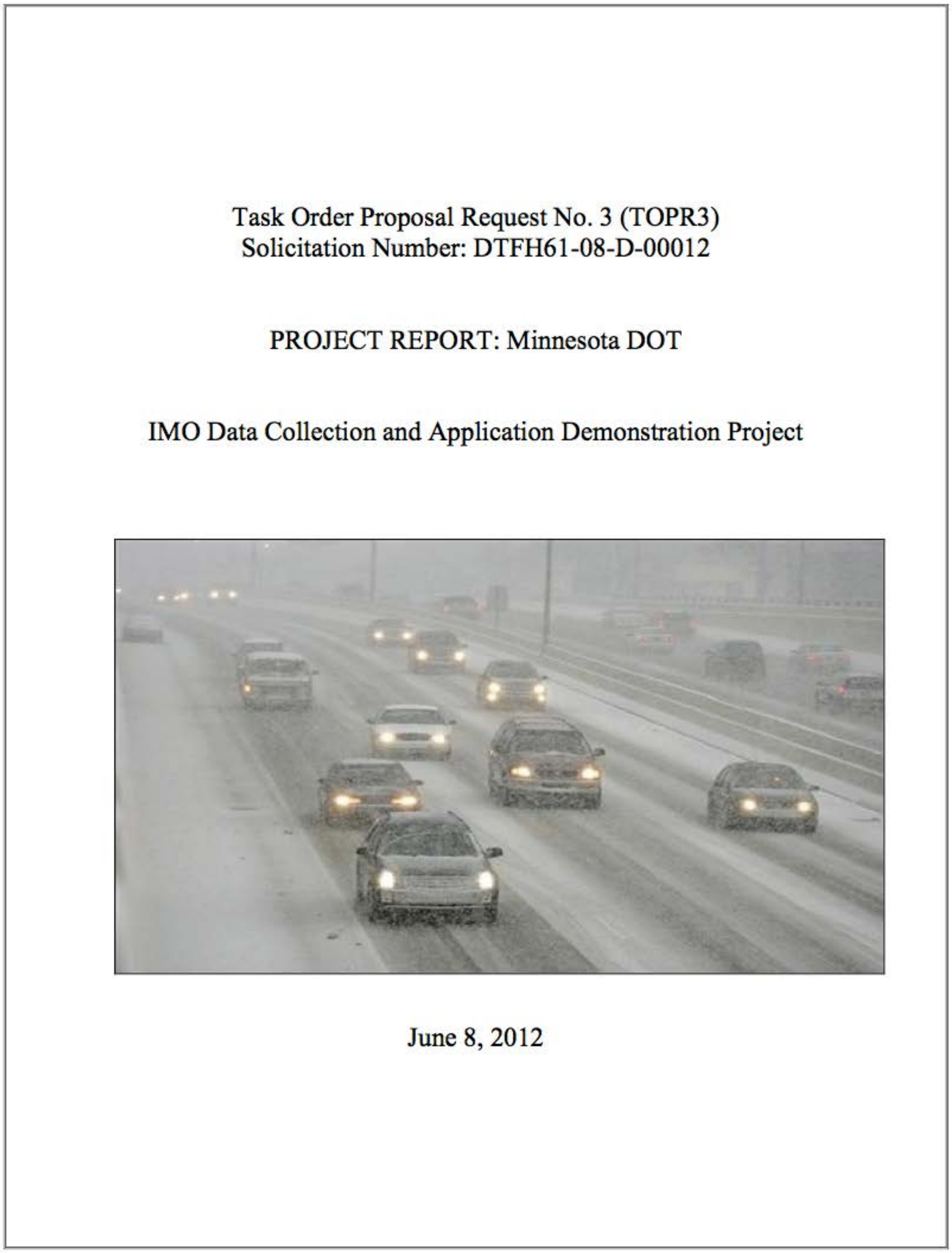
SPN #	Description	Values
114	Net battery current	-1, 254
115	Alternator current	0, 255
167	Charging system voltage	0, 3276.75
168	Battery voltage/power input 1	0 to 3277, median 14 mean 329
158	Keyswitch battery voltage	0 to 3277, median 3277 mean 2148

PGN 65272

Transmission fluids 1

SPN #	Description	Values
123	Clutch pressure	0, 4080
124	Transmission oil level	0, 10.2, 68
126	Transmission filter diff pressure	0, 510
127	Transmission oil pressure	0, 4080
177	Transmission oil temp	0 to 382, median 325.8 mean 318
3027	Transmission oil level high/low	-62.5, 63, 65
3028	Transmission oil level measurement status	0, 126, 222, 255
3026	Transmission oil level countdown timer	n/a

Appendix B



Task Order Proposal Request No. 3 (TOPR3)
Solicitation Number: DTFH61-08-D-00012

PROJECT REPORT: Minnesota DOT

IMO Data Collection and Application Demonstration Project

June 8, 2012

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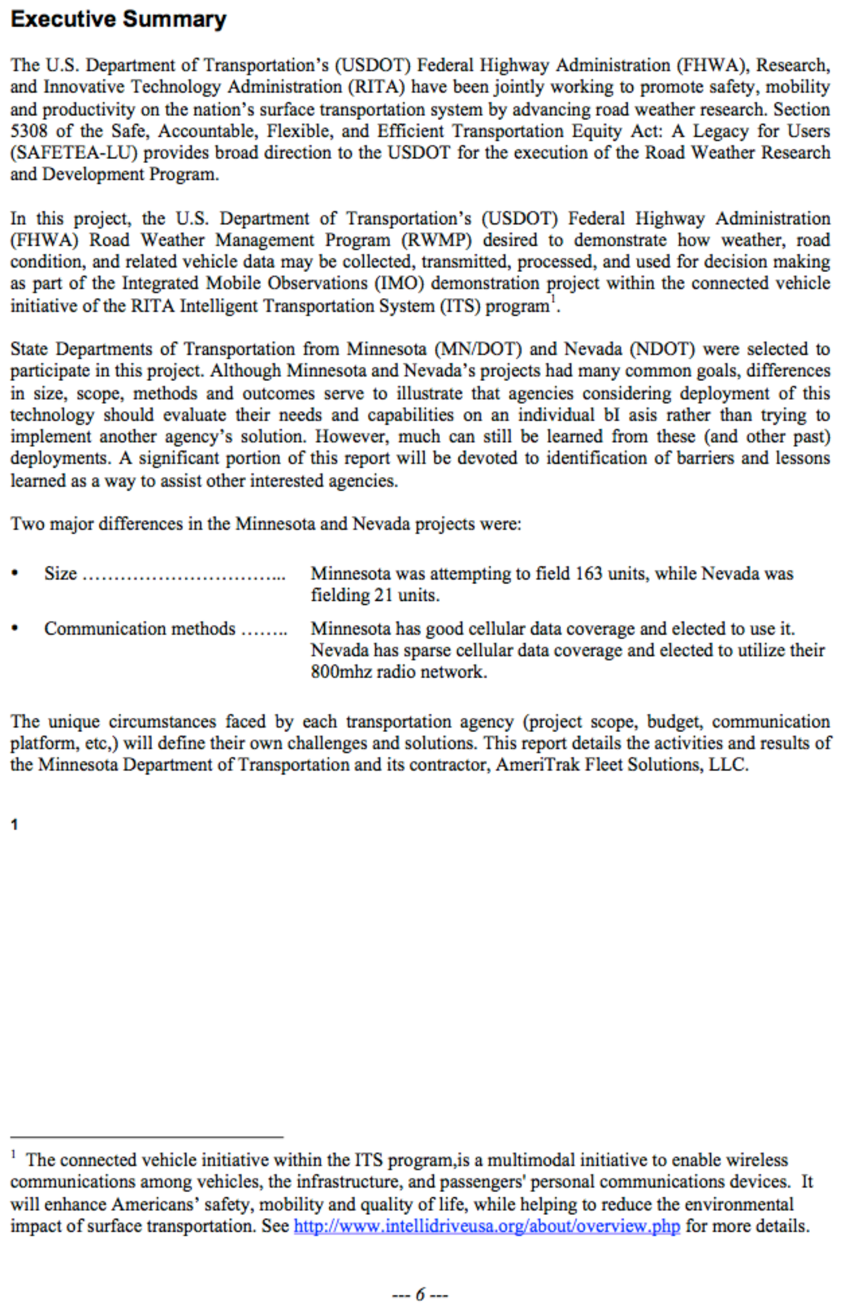
Table of Contents

ACRONYMS

ASOS	Automated Surface Observing System
AVL	Automated Vehicle Location
CAN	Controller Area Network
DOT	Department of Transportation (State or Municipal)
EMS	Equipment Management Systems
ESS	Environmental Sensor Station
FHWA	Federal Highway Administration (USDOT)
GIS	Geographic Information System
IMO	ITS Mobile Observations
ITS	Intelligent Transportation System
LRS	Linear Referencing System
M2M	Machine-to-machine communication
MADIS	Meteorological Assimilation Data Ingest System (NOAA)
MDC	Mobile Data Computers
MDSS	Maintenance Decision Support System
MMS	Maintenance Management System
MN/DOT	Minnesota Department of Transportation
NDOT	Nevada Department of Transportation
NCAR	National Center for Atmospheric Research
RITA	Research and Innovative Technology Administration (USDOT)
SAFETEA-LU	Safe, Accountable, Flexible, and Efficient Transportation Equity Act: A Legacy for Users
TIS	Traveler Information System
TOPR	Task Order Proposal Request
VDT	Vehicle Data Translator



Executive Summary

The U.S. Department of Transportation's (USDOT) Federal Highway Administration (FHWA), Research, and Innovative Technology Administration (RITA) have been jointly working to promote safety, mobility and productivity on the nation's surface transportation system by advancing road weather research. Section 5308 of the Safe, Accountable, Flexible, and Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) provides broad direction to the USDOT for the execution of the Road Weather Research and Development Program.

In this project, the U.S. Department of Transportation's (USDOT) Federal Highway Administration (FHWA) Road Weather Management Program (RWMP) desired to demonstrate how weather, road condition, and related vehicle data may be collected, transmitted, processed, and used for decision making as part of the Integrated Mobile Observations (IMO) demonstration project within the connected vehicle initiative of the RITA Intelligent Transportation System (ITS) program[1].

State Departments of Transportation from Minnesota (MN/DOT) and Nevada (NDOT) were selected to participate in this project. Although Minnesota and Nevada's projects had many common goals, differences in size, scope, methods and outcomes serve to illustrate that agencies considering deployment of this technology should evaluate their needs and capabilities on an individual bI asis rather than trying to implement another agency's solution. However, much can still be learned from these (and other past) deployments. A significant portion of this report will be devoted to identification of barriers and lessons learned as a way to assist other interested agencies.

Two major differences in the Minnesota and Nevada projects were:

- Size ………………………….. Minnesota was attempting to field 163 units, while Nevada was fielding 21 units.
- Communication methods …….. Minnesota has good cellular data coverage and elected to use it. Nevada has sparse cellular data coverage and elected to utilize their 800mhz radio network.

The unique circumstances faced by each transportation agency (project scope, budget, communication platform, etc,) will define their own challenges and solutions. This report details the activities and results of the Minnesota Department of Transportation and its contractor, AmeriTrak Fleet Solutions, LLC.

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[1] The connected vehicle initiative within the ITS program,is a multimodal initiative to enable wireless communications among vehicles, the infrastructure, and passengers' personal communications devices. It will enhance Americans' safety, mobility and quality of life, while helping to reduce the environmental impact of surface transportation. See http://www.intellidriveusa.org/about/overview.php for more details.

Project Plan

In this project, the National Center for Atmospheric Research (NCAR), MN/DOT, and AmeriTrak Fleet Solutions, LLC (AmeriTrak) partnered to obtain real-time atmospheric and vehicle data, perform data quality assessments, and use these data to support Maintenance Decision Support System (MDSS), Maintenance Management Systems (MMS), Equipment Management Systems (EMS) and Traveler Information Systems (TIS). This document outlines specific details of number and descriptions of vehicle deployments, data collection efforts, assimilation of the mobile data into specific applications, and evaluation of usefulness (or lack thereof) of mobile data into these applications.

Vehicle Deployment

Initial Deployment Plan

To support this project, MN/DOT proposed the installation of 153 AmeriTrak AT500 telematics systems mobile data computers (MDCs) integrated with the Pooled Fund MDSS system, Controller Area Network interface and other sensors. These devices were to be installed by September 2011, with data being collected through February of 2012. In order to increase vehicle type and manufacturer diversity, MN/DOT chose a mixture of vehicles listed in the Table 1:

Table 1: List of numbers, makes and models of MN/DOT vehicles that were used in the IMO project.

Count	***Model years***	***Vehicle type***
103	2004 - 2009	• Sterling LT 8511 single-axle dump trucks • Sterling LT 9511 tandem-axle dump trucks
40	2010	• Navistar International MaxForce Workstar single-axle dump trucks • Navistar International MaxForce Workstar tandem-axle dump trucks
10	2007 - 2011	Ford light duty pickup trucks

Final Deployment

As of June 18, 2012 MN/DOT has installed 161 MDC units in its vehicle fleet. Table 2 lists the deployed counts, model year and vehicle types.

Table 2: Final counts, model year and locations vehicle type for deployment of MDC units.

MDC Count	***Model years***	***Vehicle type***
114	2004 - 2009	• Sterling LT 8511 single-axle dump trucks • Sterling LT 9511 tandem-axle dump trucks
40	2010	• Navistar International MaxForce Workstar single-axle dump trucks • Navistar International MaxForce Workstar tandem-axle dump trucks
6	2007 - 2011	Ford light duty pickup trucks
1		Ford Econoline van

Figures 1, 2 and 3 show the AT500 and its mobile data terminal installed in a 2011 NaviStar WorkStar 10 (International).

Figure 1: A complete AT500 installation, as seen from the passenger side.

Figure 2: A complete AT500 installation, as seen from the operator's side.

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Figure 3: The AT500 Mobile Data Terminal (MDT).

Challenges

Although MN/DOT ended up with a larger number of installations than planned, each group of vehicles presented unique challenges. Many of the installations were either completed late in the season or had other issues preventing them from collecting and providing the full complement of data that was originally anticipated.

Installation of MDC units in the one hundred forty four 2004-2009 Sterling trucks was the single most time consuming task. All of these vehicles were already in service and housed in remote locations throughout the state. This required coordination of travel and work schedules between equipment installers and field personnel. Scheduling these installations became more difficult as winter progressed and the trucks were needed for snow and ice control. In an effort to speed up the installation process, many of these trucks had MDC units installed before the Controller Area Network (CAN) interface and other designated equipment was completed. Equipment installed later included:

- CAN-bus module and (2) cables
- ATE-SA10 Event module and cable
- Vaisala Surface Patrol temperature sensors, brackets and cabling
- Wiring to sense headlight and windshield wiper status

The reason for this decision was simply to expedite MDC installation and begin partial data collection. It was felt that personnel could modify the installations later and accommodate the additional equipment faster than waiting for all equipment and performing a complete installation. Although effective at getting the base mechanical package and wiring in place, this strategy had the effect of compounding travel and work schedule issues with many of the trucks, requiring several visits to install new components and/or new versions of software before they were fully functional.

Installation of the MDC units on the 2010 International Navistar trucks was accomplished at MN/DOT's central equipment shop. This greatly reduced travel and scheduling conflicts with field personnel. The installations went well and the newer model trucks provided a much more robust set of CAN-bus parameters. However, installation of snow and ice equipment on the International trucks (i.e., plows, spreader equipment, etc.) did not progress as quickly as hoped and very few of these new trucks were delivered in time to collect data in the field.

AT500 General Features

The AT500 is a robust, general-purpose mobile computing platform. Its features are described as follows:

General
- Fanless, compact, embedded chassis
- Cast aluminum rugged sealed enclosure
- Embedded 50-channel WAAS-corrected GPS receiver

Power
- Operational with both 12-volt and 24-volt systems
- Power ignition status monitor and system on/off auto control
- 5-V and 12-V (1-A) regulated power output
- 1.11A Idle, 1.32A Running, 800mA Suspend, 10mA Off

Chipset
- Intel® Atom N270 CPU at 1.6 GHz
- Intel 945GSE / ICH7M

Memory and Storage
- 1 or 2-G DDR2 SDRAM (internal memory)
- SATA solid-state disk drive (any size > 10Gig)
- Type II CompactFlash socket

Display Support
- VGA and LVDS dual independent display

Communication
- Optional built-in WLAN/GPRS/EDGE/UMTS/HSDPA module
- USB modem devices for all carriers

Ports
- 4 serial: 3 RS-232 and 1-RS-232/RS-422/RS-485
- 4 USB
- 10/100/1000 Ethernet LAN port

General Purpose I/O (GPIO)
- Isolated digital inputs and 2 digital outputs (expandable)

Audio
- Microphone inputs and 2 Audio line outputs
- Audio amplifier supports stereo at 6W

`Certifications`

- ISO-7637-2
- CE
- FCC Part 15 Class B
- e13 Mark
- EN50155
- IP40 and IP65 Protection Class

`Operating Systems`

- Microsoft XP
- Linux

`Environment Specs`

- -30 to +60 C Operating temperature range
- 10-90% non-condensing relative humidity
- Random vibration: 2g at 5-500 Hz
- Operating vibration, shock and crash hazard: MIL-STD-810F

Heavy Truck CAN Interface Development

Initial Plans

The Team's initial goal was to implement the heavy truck J1939 CAN-bus interface first, then move onto the light-duty truck OBD-2 J1979 CAN-bus interface. Although other hardware datalink interfaces exist in most vehicles, the CAN-bus, present on both classes of vehicles (heavy duty vs. light duty and passenger cars), is where the Team focused its development efforts.

In order to accomplish this quickly, the Team chose to deploy a common, inexpensive, in-vehicle CAN-bus interface well known in hobbyist circles, the ELM-327 (ScanTools.com). A new embeddable module implementing the full ELM-327 interface from ScanTools.com was noticed. This new module now included the J1939 protocol, the interface used exclusively in heavy trucks. A circuit was designed around this new module, parts were ordered and prototypes were quickly built. Initial results from this effort were disappointing and frustrating.

Challenges

Using this first circuit, the Team was unsuccessful at acquiring any meaningful data from either Sterlings or Internationals. An extensive review of this initial design, as well as close examination of the heavy truck's datalink, revealed the following problems:

- Many firmware bugs were present in the new off-the-shelf ELM-327 module
- The new ELM-327 module poorly supported the more complex J1939 protocol
- An enormous amount of data is moving very quickly on the modern vehicle datalink
- Our simplistic circuit built around the ELM-327 module was quickly overwhelmed by the scale and speed of the datalink information

Support from ScanTools.com was insufficient, compounding the above problems. It became clear that none of the ELM-327 interfaces were going to be able to keep up with the volume and speed of data MN/DOT and FWHA desired to collect.

Results

The lack of success with the new ELM-327 module resulted in the need to develop a new, custom design featuring a much faster microprocessor, a faster CAN-bus interface and a faster communication interface; in other words, a completely new design was called for late in the project. Because the Team had to move quickly, an independent contractor was hired to help with the new hardware design. In addition to the much faster speed of the new custom hardware, a completely new, very efficient firmware design was also implemented. However, the new module's hardware and software design also required a complete re-write of the AT500's CAN-bus software interface.

Finally, in late August 2011, meaningful CAN-bus data was being acquired. Real time translation of the raw J1939 CAN-bus payloads to human-readable form was accomplished in mid-September 2011.

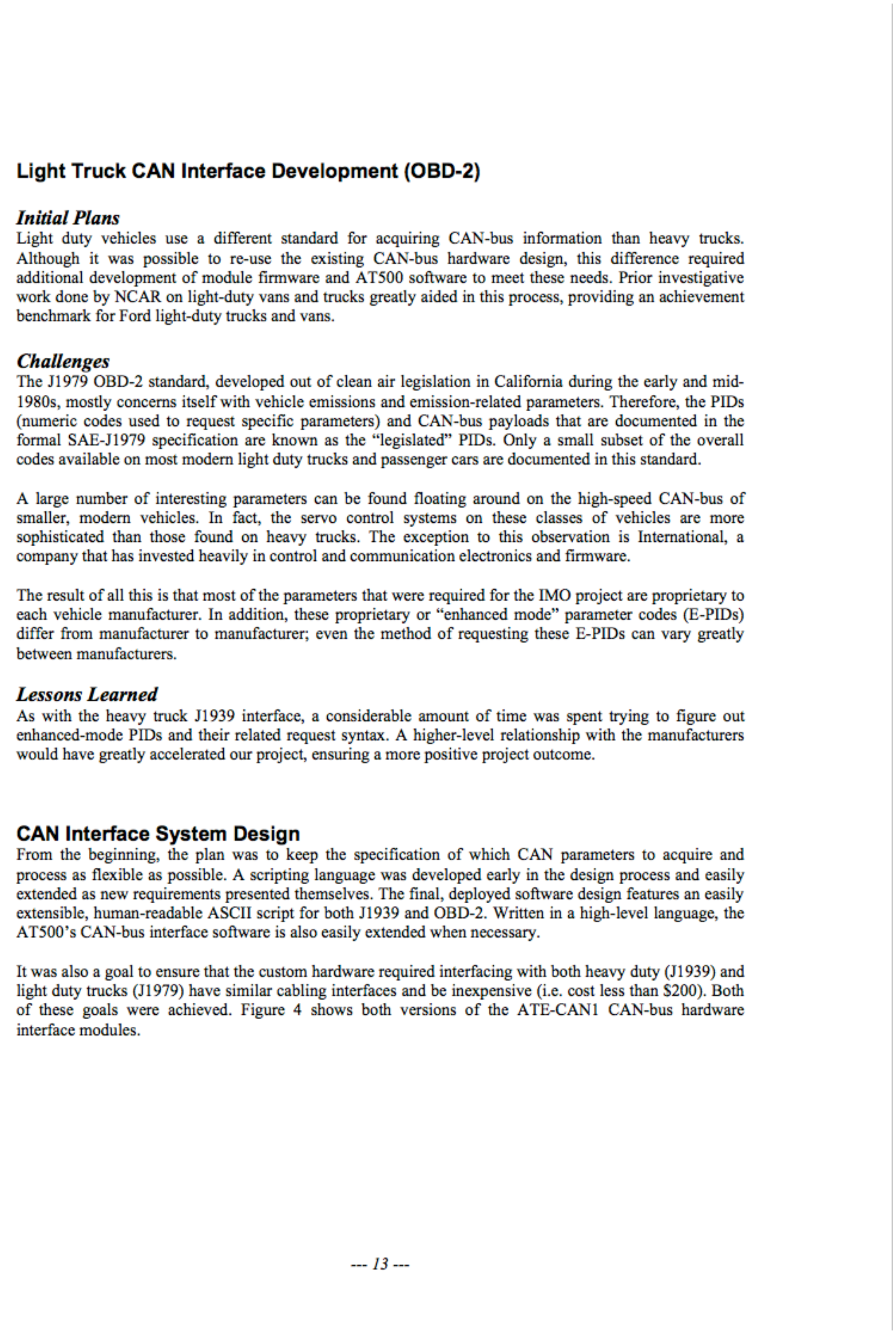
To avoid problems encountered during partial installations on Sterlings, one example truck was used for the entire development process. When data were successfully collected and demonstrated, additional units were installed in similar vehicles. All vehicles installed with the CAN-bus hardware are currently collecting and sending data.

Lessons Learned

The specification for heavy truck CAN-bus implementation, SAE-J1939, is very complete and offers a rich and descriptive data set. In fact, every parameter required of MN/DOT, as published in the Required Parameter Table (See Appendix C), can be found in this document. Unfortunately, heavy truck manufacturers are free to implement as much or as little of the specification as they wish. In fact, many of the parameters that may contain a data item of interest to our project may be present in the spec, but turned out to contain no data when monitored or queried. It is possible that the manufacturer implemented the given data item as an internal, proprietary parameter, which left little to no access for the project.

Early in our project, higher-level talks between MN/DOT Management and their peers at Sterling and International should have taken place to ask for help with those proprietary PGNs and SPNs, that would have enabled access to data items required by FHWA and NCAR. A considerable amount of time could have been saved, accelerating our project completion.

A positive note with the International Navistar trucks is that representatives from International were contacted and engaged concerning proprietary CAN-bus data. After introducing International representatives to the joint MN/DOT -- IMO project concept and allowing them to observe some of the acquired data at a recent trade show, International now sees value in this project and expressed a willingness to help develop in-vehicle software interfaces that would allow MN/DOT to acquire and display previously unavailable CAN-bus parameters. This work with International is progressing quickly, and should be completed at or before the time of a possible Phase-II of the IMO project begins.



Light Truck CAN Interface Development (OBD-2)

Initial Plans

Light duty vehicles use a different standard for acquiring CAN-bus information than heavy trucks. Although it was possible to re-use the existing CAN-bus hardware design, this difference required additional development of module firmware and AT500 software to meet these needs. Prior investigative work done by NCAR on light-duty vans and trucks greatly aided in this process, providing an achievement benchmark for Ford light-duty trucks and vans.

Challenges

The J1979 OBD-2 standard, developed out of clean air legislation in California during the early and mid-1980s, mostly concerns itself with vehicle emissions and emission-related parameters. Therefore, the PIDs (numeric codes used to request specific parameters) and CAN-bus payloads that are documented in the formal SAE-J1979 specification are known as the "legislated" PIDs. Only a small subset of the overall codes available on most modern light duty trucks and passenger cars are documented in this standard.

A large number of interesting parameters can be found floating around on the high-speed CAN-bus of smaller, modern vehicles. In fact, the servo control systems on these classes of vehicles are more sophisticated than those found on heavy trucks. The exception to this observation is International, a company that has invested heavily in control and communication electronics and firmware.

The result of all this is that most of the parameters that were required for the IMO project are proprietary to each vehicle manufacturer. In addition, these proprietary or "enhanced mode" parameter codes (E-PIDs) differ from manufacturer to manufacturer; even the method of requesting these E-PIDs can vary greatly between manufacturers.

Lessons Learned

As with the heavy truck J1939 interface, a considerable amount of time was spent trying to figure out enhanced-mode PIDs and their related request syntax. A higher-level relationship with the manufacturers would have greatly accelerated our project, ensuring a more positive project outcome.

CAN Interface System Design

From the beginning, the plan was to keep the specification of which CAN parameters to acquire and process as flexible as possible. A scripting language was developed early in the design process and easily extended as new requirements presented themselves. The final, deployed software design features an easily extensible, human-readable ASCII script for both J1939 and OBD-2. Written in a high-level language, the AT500's CAN-bus interface software is also easily extended when necessary.

It was also a goal to ensure that the custom hardware required interfacing with both heavy duty (J1939) and light duty trucks (J1979) have similar cabling interfaces and be inexpensive (i.e. cost less than $200). Both of these goals were achieved. Figure 4 shows both versions of the ATE-CAN1 CAN-bus hardware interface modules.

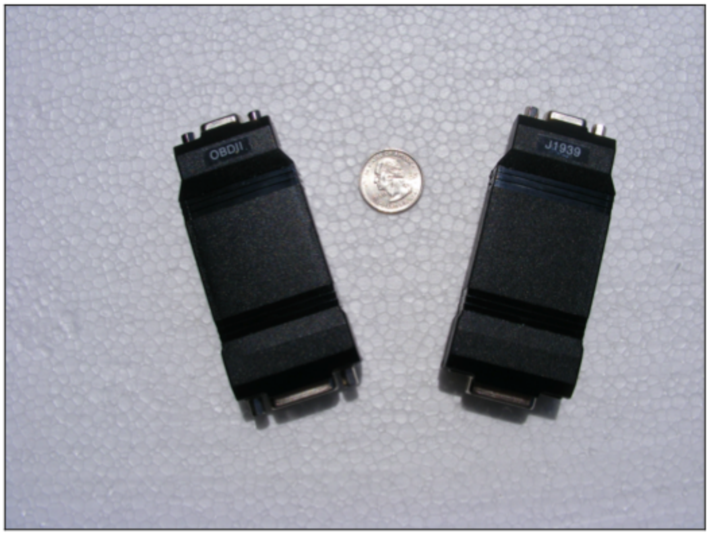


Figure 4: The ATE-CAN1 CAN-bus interface modules for OBD-2 (left) and J1939 (right).

Alternate Interface Box Development

Once the CAN-bus interface was installed, it was determined that several of the CAN parameters desired by FHWA and NCAR were either not being collected by the older vehicles or were contained within proprietary portions of the CAN-bus data. This data would not be available without specialized help from the manufacturer or developers of scan tools designed to extract this information.

As a work-around, external sensors and an interface box, the ATE-SA10, was developed by MN/DOT's contractor and added to the equipment mix. The addition of the ATE-SA10 meant that additional desired information, not found on the CAN-bus on older trucks, could now be collected. While this was effective at obtaining the necessary data, it became yet another delay to the completion of this project.

The ATE-SA10, shown in Figure 5, is a microprocessor-based, +12V general-purpose event input device with the following features:

- 5-Active inputs for wipers, lights, etc. (+4V to +36V DC)
- Precipitation sensor input, including isolated power for the sensor
- Sun sensor input, including isolated power for the sensor
- 3-axis accelerometer
- RS-232 serial I/O for the Vaisala Surface Patrol and Surface Patrol HD temperature sensor
- RS-232 serial I/O interface to the AT500 or other host computer

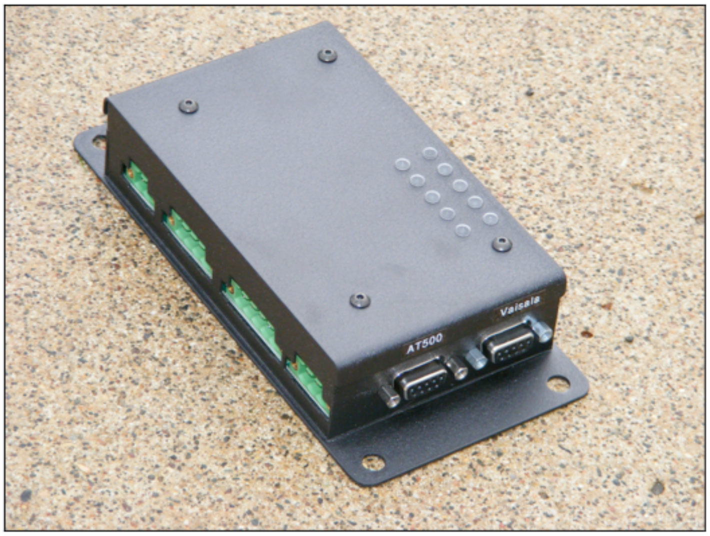


Figure 5: The ATE-SA10.

Servers

During mid-June through mid-July of 2011, MN/DOT's contractor reorganized its logical server chain. These changes were necessary to accommodate ten new data messages, allowing NCAR, *Clarus* and Meridian to accept an enhanced real time data feed. During the software development effort, which enabled the addition of new messages, several changes were made to each server, including mechanisms that would allow new data messages to be easily added as new requirements arose or as changes to existing messages were required.

Communication

Communication from the AT500 mobile computing platform to the Data Center, located in downtown Minneapolis, was accomplished through the Verizon cellular network.

The State of Minnesota enjoys good cell coverage. However, there are many locations throughout rural Minnesota where tower "hand-offs" from one cell to another cause the AT500 to loose its connection. In order to provide near-seamless cellular connectivity, it was necessary to write a customized connection manager to solve frequent disconnection events.

Routes

Initial Plan

Supply NCAR and *Clarus* with identifiers and coordinates for all MDSS routes involved in the IMO project.

Results

MN/DOT was able to supply NCAR and *Clarus* with identifiers and coordinates for all MDSS routes involved in the IMO project. A map of these routes is shown in Figure 6, below.

Challenges

Although MN/DOT had the necessary route data to populate this map, it was stored in multiple locations and, in some cases, multiple data formats and versions. To facilitate data sharing in MDSS and other applications using routing or other MN/DOT GIS data, it is necessary for MN/DOT to make one or more of the following changes:

- Integrate GIS data storage in one system
- Develop a system to combine data into one easily accessible format
- Modify current internal processes so requested data can be stored and accessed electronically without the need to manually review and edit data from multiple systems to get the desired results.

MN/DOT is presently addressing this and similar issues by developing a Linear Referencing System (LRS).

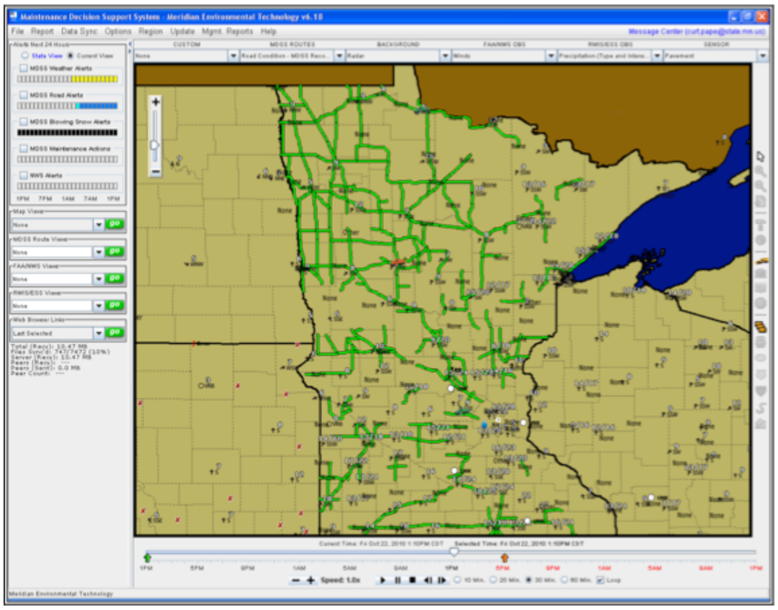


Figure 6: MnDOT routes for the IMO project

Comparison of Vehicle Mounted Air and Pavement Temperature Sensors

Initial Plans

- Purchase and install 50 Vaisala Surface Patrol temperature sensors.
- Collect data and compare with data from existing Sprague RoadWatch temperature sensors.
- Produce a report on accuracy and durability.

Surface validation will be based on *Clarus* data. See Figure 8 for an example of the *Clarus* surface temperature readings from February 29, 2012.

Results

Vaisala equipment was ordered and received by MN/DOT. Once received, Vaisala discovered that they had loaded incorrect firmware on a portion of the units. All units were shipped back and had the problem corrected.

The Sprague temperature sensors MN/DOT currently uses have an interface to the Dicky-John Control Point and report their values through the Dicky-John controller. Vaisala temperature sensors do not interface with the Dicky-John controller, so an interface with the telematics unit needed to be created. Both sensors are shown in Figure 7. Vaisala was very forthcoming with this information, and the Team quickly developed a functional interface to collect and display pavement and air temperature data.

In the end, data was collected from many RoadWatch sensors and approximately 10 Vaisala sensors. This data was fed into *Clarus* and displayed on an electronic map similar to the one shown in Figure 8.

Surface Patrol RoadWatch

Figures 7: Vaisala Surface Patrol HD and Sprague Road Watch temperature sensors.

Challenges

The Vaisala sensors and controllers MN/DOT received had several different versions of firmware installed on them. Not all firmware versions collected data reliably. MN/DOT's contractor is working with Vaisala to identify the cause of this problem and implement a solution.

Mounting brackets supplied with the Vaisala units appeared to be designed for light duty vehicles and did not work well in the harsh environment snowplows operate in. MN/DOT was able to design brackets specifically for the Sterling (West Coast style mirror) and Navistar (mount on one large arm). On a normal research project MN/DOT would have designed and built a functional bracket for the test units without worrying about scalability. Since this project was tied-in with a statewide deployment, MN/DOT carefully documented their design, specifications, and testing to ensure a supportable product throughout the fleet. Ultimately manufacturing of these brackets will be done by an external vendor. Figure XXX and YYY show photos of the mounting brackets for Sterling and Navistar trucks.

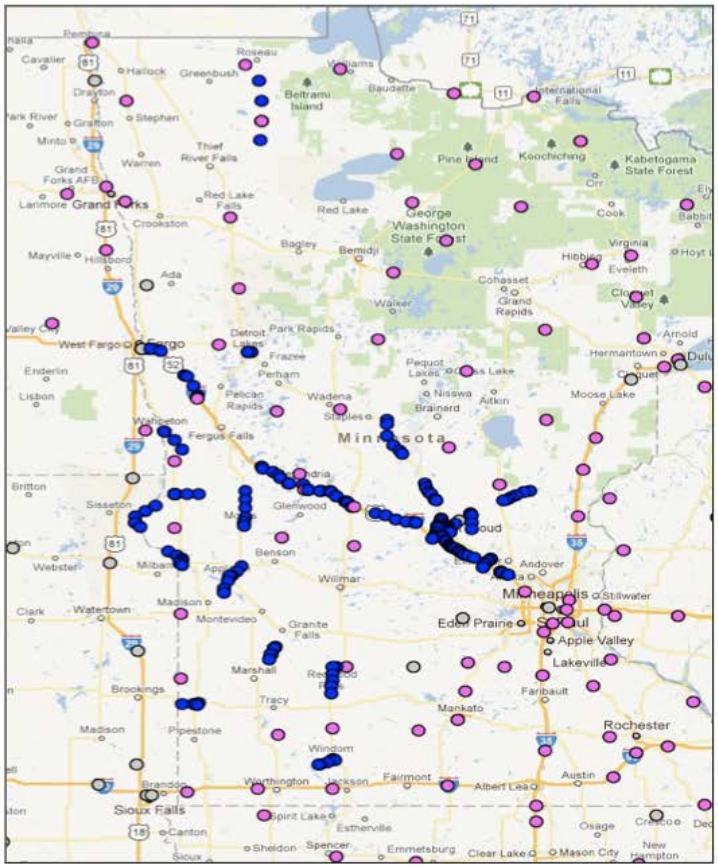


Figure 8: Minnesota *Clarus* data, showing surface temperature from February 29, 2012. Mobile observations are shown in blue.

Collection of Humidity Readings

Initial Plans

NCAR felt that it would be useful to piggyback onto the temperature sensor test and add 25 Vaisala Surface Patrol HD sensors to the test. These sensors collect air and pavement temperatures like the standard Surface Patrol, but also have the ability to take relative humidity readings. NCAR felt that relative humidity would be a valuable parameter to collect from mobile platforms, and wished to collect this data so comparisons could be made with data obtained from fixed sites to study the effect this data has when added to weather models or processed by the Vehicle Data Translator (VDT).

Results

Only 2 HD sensors were successfully added to snowplows. This was done at such a late date that no data was available to study the effects of mobile humidity readings.

Challenges

Humidity readings are most useful in the hours leading up to a storm. Typically, MN/DOT snowplows are not active until very near or at the onset of precipitation -- too late to gain much value from this data. To mitigate the problem, Humidity Sensors should be targeted to patrol or other vehicles that are routinely active before inclement weather arrives.

Additionally, the Vaisala sensor design requires air to flow freely around and through the sensor as the vehicle moves. This could be problematic in the harsh environments snowplows typically operate in, and MN/DOT feels the sensor has a high potential to become damaged or clogged with snow and ice if mounted on snowplows.

Collection of Precipitation Data

Initial Plans

Outfit six vehicles with radar precipitation sensors and evaluate data from these units against fixed RWIS sensors.

Results

The sensors MN/DOT planned on using were not fully developed for a mobile application and were not used. Exploration into the subject yielded a potential replacement sensor which would provide rudimentary precipitation information, but the interface between this sensor and the mobile data equipment was not completed in time to test.

Challenges

Commercially available precipitation sensors are designed to be mounted on fixed platforms. MN/DOT was not able to locate a radar precipitation sensor designed for use on a mobile platform.

Collection of Camera Imagery

Initial Plans

MN/DOT proposed to mount video cameras and transmit streaming video from mobile platforms in ten vehicles. It was felt that this info would be useful in verifying local conditions, including visibility, precipitation and validation of VDT output.

Results

MN/DOT's contractor already had in-vehicle video software developed and deployed for other applications. This existing in-vehicle video software was modified and applied to the AT500 for the FHWA IMO project.

The camera software was originally designed for school bus applications where GPS and other time/location-stamped data are associated with streaming video. The original software package records and stores streaming video from as many as four in-cabin IP[2] cameras, then offloads the captured video data using wifi (802.11N) when the vehicle returns to its central location. All GPS and other time/location-stamped data are transmitted in real time as it is acquired.

Due to the many other delays experienced throughout this project, development of the video application did not occur until late in the project. MN/DOT got only one of the ten planned cameras installed and operational. However, screen shots from this camera (Figure 9) demonstrate that good quality images can be generated with a relatively inexpensive camera.

Challenges

The modifications to this original package, in order to implement camera imagery as a required parameter for the FHWA IMO project, include the following:

- Rather than acquire streaming video, a 640 x 480 full color snapshot (image) is acquired and stored on the AT500's hard disk.
- This image is also immediately transmitted to the web server for archival.
- An in-vehicle web site implemented on the AT500 is provided for local image browsing and downloading.
- An additional web site was implemented on the central web server to provide image browsing and downloading for the entire fleet of camera-equipped vehicles.

Collection, transmission and storage of streaming video pose significant data storage needs. Resolution, frequency, storage and dissemination of such information need to be well planned out or it could quickly overwhelm the user's system.

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[2] IP camera, in this instance, means a small format video camera whose output is a consolidated video and audio Ethernet signal.

Figure 9: A photo from AT500's dash-mounted video camera.

Data Collection and Transmission

Results

Data from the MN/DOT IMO project was collected using AT500 MDCs. Data was transmitted via cellular data service, stored on the servers operated by MN/DOT's vendor, and disseminated to users (i.e. *Clarus* and NCAR) using a real time TCP/IP interface. A website for MN/DOT users was provided to view the data, and a data dictionary was compiled, allowing *Clarus* and NCAR to receive and reassemble the data in near-real time. In cases where the cellular communication network was temporarily unavailable, data was held on the AT500 and forwarded when communication was restored. Appendices C and D detail the parameters collected, the method or methods employed to collect each parameter, and the location and status of each parameter.

Challenges

Data was successfully collected, stored and forwarded to MN/DOT, *Clarus*, and NCAR. All desired parameters were tested to see if they were present on the datalink. However, availability of CAN-bus information varied greatly by vehicle type, model year and manufacturer. In general, light duty vehicles have a more robust data set than heavy trucks, but data availability in newer model heavy trucks is improving greatly.

Data storage, transmission, processing, and display requirements increased exponentially depending on what CAN-bus and external sensor parameters were selected. Pre-processing on the mobile units and adjustments to the frequency of collection were some of the solutions implemented to reduce data volume.

Lessons Learned

An automated machine-to-machine or M2M update mechanism for downstream agency data consumers also needs to be developed and employed. This will allow changes to unit configurations, sensors and other parameters to be quickly and easily communicated to all users of this data. Any "store and forward" mechanism with respect to system-level data consumers must also be robust enough to determine what data has been successfully transmitted and what may have become lost in the event a data consumer front-end loses its connection to the Data Center. If these system-level changes are not addressed, glaring "holes" in the consumed downstream data will be present.

The Team did not anticipate the need for M2M system-level tools, specifically the transmission of information regarding the number of installed vehicles, the types of sensors and equipment installed on each vehicle, and the replacement or movement of AT500s from vehicle to vehicle. These automated M2M mechanisms will be addressed during the summer of 2012.

Applications

The primary purpose for mobile data being collected in MN/DOT is to provide raw data to and receive processed data from the Pooled Fund MDSS. In addition to MDSS, MN/DOT desires to use this data to automate several processes now being completed manually. These processes include feeding data to the following:

- MMS
- EMS
- Pubic Information Systems (i.e. 511 and related public websites).

Other applications for this data include providing automated notifications and information to fleet maintenance personnel when the vehicle generates a serious error code.

MDSS

Data collected and transmitted to MDSS include the following:

- Material type and rate, as reported by attached sander equipment
- Air and pavement temperature, as reported by attached sensors
- Weather and surface conditions, as reported by driver (via touch screen input)
- Vehicle speed and position, as reported by GPS coordinates

Data processed and transmitted by MDSS include the following:

- Radar and weather forecasts
- Chemical type and application rate recommendations
- Positions of nearby maintenance vehicles

MN/DOT has been actively involved with MDSS since its inception and is in the process of deploying this technology statewide. Past experience with MDSS has demonstrated that mobile data collection plays an important role in gaining widespread acceptance of this technology. MDSS is a powerful management tool but represents a significant culture change to most DOTs. It can be rejected by end users if deployment isn't accompanied by rigorous training and support. Mobile data provides the means to collect disseminate and display information needed to build operator confidence and indicates where further support is needed. It also allows managers to review past actions and evaluate what changes are needed to further improve efficiency. Figures 10 and 11 show examples of in-vehicle screens available to MN/DOT snowplow truck operators.

MN/DOT has successfully used this data to demonstrate a benefit/cost potential of 6/1 or greater could be achieved with a statewide deployment of MDSS and Mobile Data Collection technologies. Yearly savings will vary by region and agency, but for MN/DOT a 6/1 benefit would equate to over $4,000,000 per year savings in salt alone. Along with the cost savings and environmental benefits of using less salt, MN/DOT also anticipates a reduction in fuel and equipment costs. Further details on MN/DOT's cost study are contained in Appendix A.

As stated above and confirmed by user surveys, addition of mobile data collection to MN/DOT's MDSS deployment project has led to improved operator acceptance and greater use of MDSS recommendations. Having access to the latest radar information, viewing locations of nearby trucks, and automatically sending information on current road condition, truck speed/location, amount of chemical applied are all factors which help operators gain confidence in the system and take intelligent risks when appropriate.

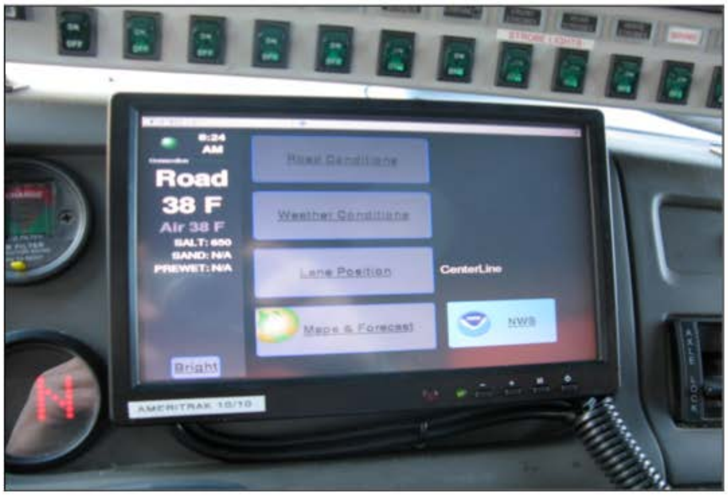


Figure 10: The AT500's MDT displaying the Main Screen.

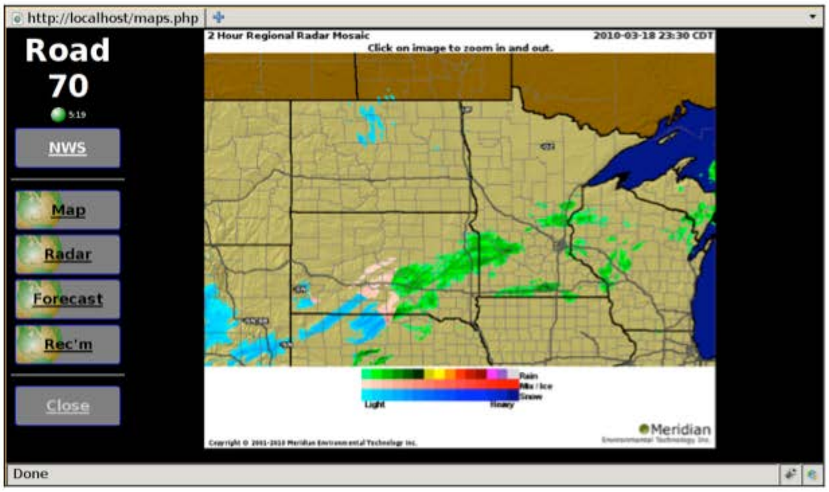


Figure 11: The AT500's MDT displaying one of the animated weather screens.

MMS/EMS

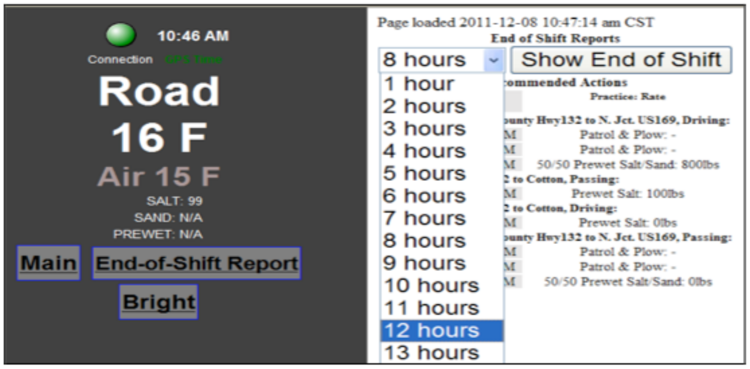
Maintenance Management Systems (MMS) and Equipment Management Systems (EMS) are becoming increasingly important in Performance Measurement and/or Business Planning efforts being conducted by State, County and Local DOTs. Data input to these systems is used to track performance and improve efficiencies of these agencies.

Currently, almost all of the data collected by these systems requires manual input. This manual input is time consuming and frequently subject to errors. These shortcomings can be widespread enough to lower the value of data which is output by these systems.

For this test, data received from trucks was processed by MDSS to generate an "end of shift" report detailing the following:

- The number of passes
- The type and amount of chemical applied
- The end of event time
- The time bare pavement was regained
- Total hours of operation

This report was used by operators to enter information required by Maintenance and Equipment Management Systems. The report reduced the time required by operators to input their end-of-shift information and increased the accuracy of information reported. This is viewed as an interim step towards development of fully automated interfaces to MMS and EMS. Short time frames for the use of these reports preclude MN/DOT from producing a defensible benefit/cost study at this point. Operator surveys demonstrated a high level of satisfaction with the "end of shift" reports and continued support to fully automate the processes. Operators also felt that they were able to reduce the time spent entering this information and increase the accuracy of the end-product. Examples of MN/DOT's "end of shift" report are shown in Figures 12 and 13, below.



10:46 AM

Road
16 F
Air 15 F
SALT: 99
SAND: N/A
PREWET: N/A

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End of Shift Reports

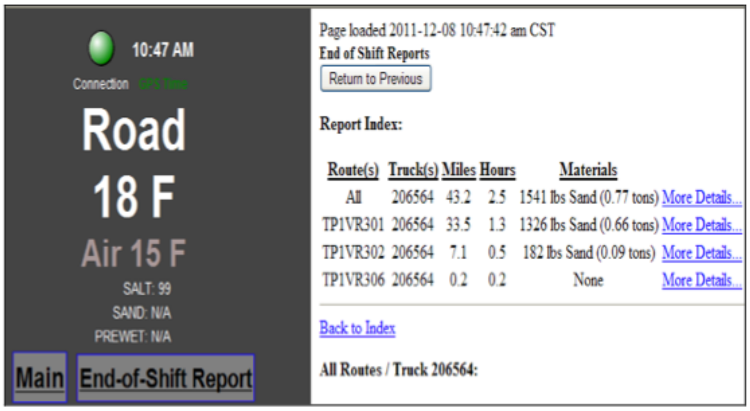
8 hours

ommended Actions

Practice: Rate

ounty Hwy132 to N. Jct. US169, Driving:
M Patrol & Plow: -
M Patrol & Plow: -
M 50/50 Prewet Salt/Sand: 800lbs
2 to Cotton, Passing:
M Prewet Salt: 100lbs
2 to Cotton, Driving:
M Prewet Salt: 0lbs
ounty Hwy132 to N. Jct. US169, Passing:
M Patrol & Plow: -
M Patrol & Plow: -
M 50/50 Prewet Salt/Sand: 0lbs

Figure 12: The AT500's MDT displaying the Main End-of-Shift Report Screen.



10:47 AM

Road

18 F

Air 15 F

SALT: 99

SAND: N/A

PREWET: N/A

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End of Shift Reports

Report Index:

Route(s)	Truck(s)	Miles	Hours	Materials	
All	206564	43.2	2.5	1541 lbs Sand (0.77 tons)	More Details...
TP1VR301	206564	33.5	1.3	1326 lbs Sand (0.66 tons)	More Details...
TP1VR302	206564	7.1	0.5	182 lbs Sand (0.09 tons)	More Details...
TP1VR306	206564	0.2	0.2	None	More Details...

All Routes / Truck 206564:

Figure 13: The AT500's MDT displaying a follow-on End-of-Shift Report Screen.

Traveler Information

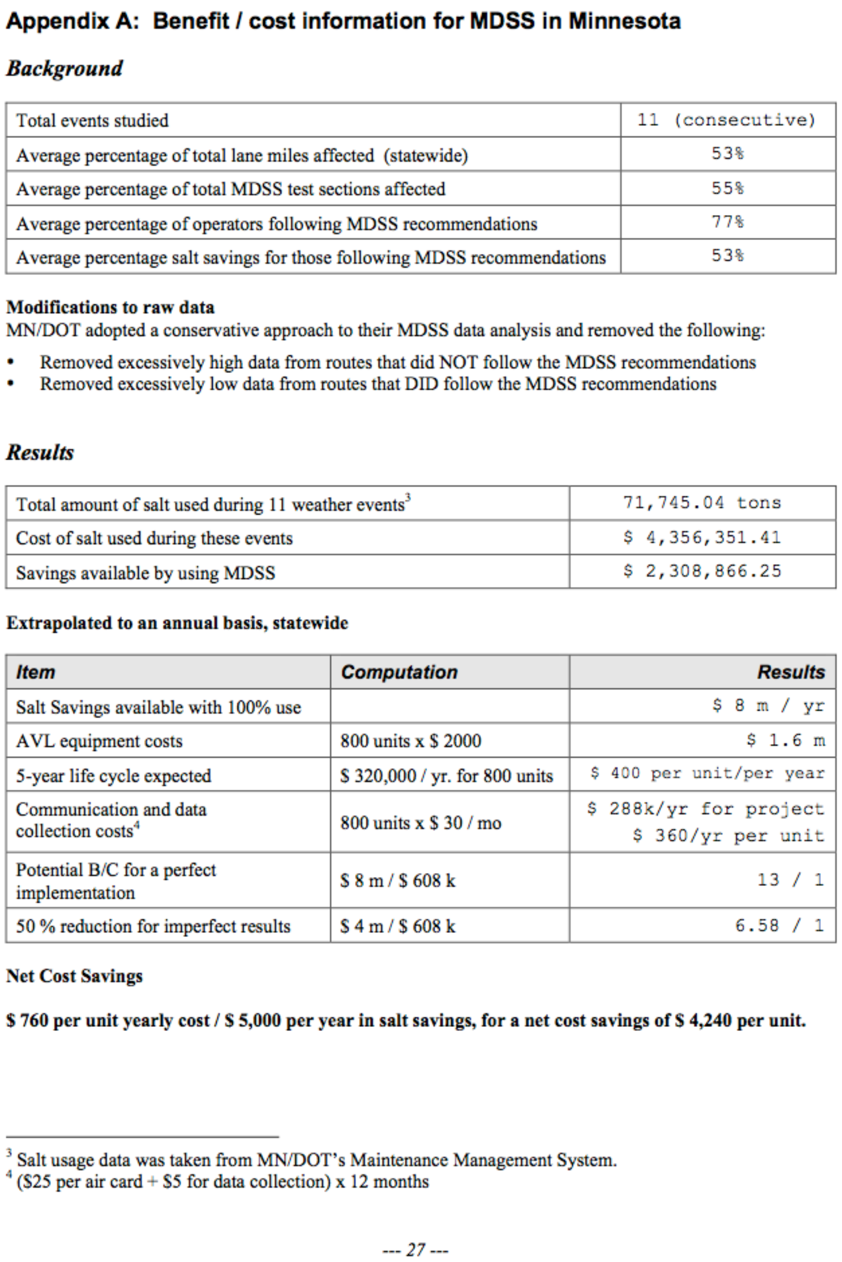
The ability to provide enhanced weather and traffic could result in tremendous benefits. Mobile data collected during this project provides one of the best opportunities to enhance traveler information, but as of yet, we know too little about how the traveling public integrates road weather information into their decision-making processes. In a perfect world, we would expect that providing better road and weather warning information would lead to increased protective action on the part of the traveling public. However, there is a rich social science literature indicating that people do not respond to warnings and weather information in a linear manner. Information systems comprise both scientific technologies and the people who use them. Importantly, people bring significant perceptual and behavioral histories to the decision-making table.

Results

Due to project delays, MN/DOT was not able to explore the full benefits of the automated collection and reporting of traveler information as planned. MN/DOT still feels there is significant potential in this area and proposes to investigate this further in during Phase 2 of the IMO project if given a chance to participate.

Summary of lessons learned

- The MN/DOT IMO project was a large-scale deployment and as such generated information on multiple levels. While equipment and methods are an important part of any project, a large project tends to highlight the need for monitoring and tracking project progress. Much like a road construction project has well defined requirements, schedules and critical paths, a large MDSS and/or AVL deployment will struggle without the use of some type of planning and tracking software. In addition to tracking resources, progress and future activity, we feel it is necessary to consider the needs of end users and build-in features which minimize the impact of changes to data format and/or individual message content. In MN/DOT's case, these end users include MDSS (operated by Meridian Environmental Technology), Clarus (operated by Mixon Hill), NCAR, and MN/DOT's internal users. To meet the needs of these users, configuration data and other project related progress information must be supplied and updated on a continuous basis.
- Availability and location of CAN-bus information varies by manufacturer, model year, and vehicle type. There are several approaches to dealing with this issue; most have both good and bad points. The project did not find any "off the shelf" item that could be considered a clearly outstanding solution. However, many of these barriers can be identified and solved if an agency can establish an open relationship with the vehicle manufacturer.
- Collection, transmission and storage of CAN-bus parameters can generate a significant amount of data, Development of a system should begin with careful planning involving the specific parameters and frequency of data gathered so an agency does not encounter bottlenecks in one or more areas.
- Development and delivery of training materials, adoption of a "standard" installation package, and easy access to support personnel play a key role in acceptance of new technologies such as MDSS and AVL.
- Start slow, walk carefully and make sure you have long-term support instead of taking a shotgun approach when deploying something that represents a significant change from the current or accepted way of doing business in your agency.
- Don't be discouraged when the project runs into barriers, this is how you learn which elements are unique and important in your agency and tailor the project to meet those needs.



Appendix A: Benefit / cost information for MDSS in Minnesota

Background

Total events studied	11 (consecutive)
Average percentage of total lane miles affected (statewide)	53%
Average percentage of total MDSS test sections affected	55%
Average percentage of operators following MDSS recommendations	77%
Average percentage salt savings for those following MDSS recommendations	53%

Modifications to raw data

MN/DOT adopted a conservative approach to their MDSS data analysis and removed the following:

- Removed excessively high data from routes that did NOT follow the MDSS recommendations
- Removed excessively low data from routes that DID follow the MDSS recommendations

Results

Total amount of salt used during 11 weather events[3]	71,745.04 tons
Cost of salt used during these events	$ 4,356,351.41
Savings available by using MDSS	$ 2,308,866.25

Extrapolated to an annual basis, statewide

Item	*Computation*	*Results*
Salt Savings available with 100% use		$ 8 m / yr
AVL equipment costs	800 units x $ 2000	$ 1.6 m
5-year life cycle expected	$ 320,000 / yr. for 800 units	$ 400 per unit/per year
Communication and data collection costs[4]	800 units x $ 30 / mo	$ 288k/yr for project $ 360/yr per unit
Potential B/C for a perfect implementation	$ 8 m / $ 608 k	13 / 1
50 % reduction for imperfect results	$ 4 m / $ 608 k	6.58 / 1

Net Cost Savings

$ 760 per unit yearly cost / $ 5,000 per year in salt savings, for a net cost savings of $ 4,240 per unit.

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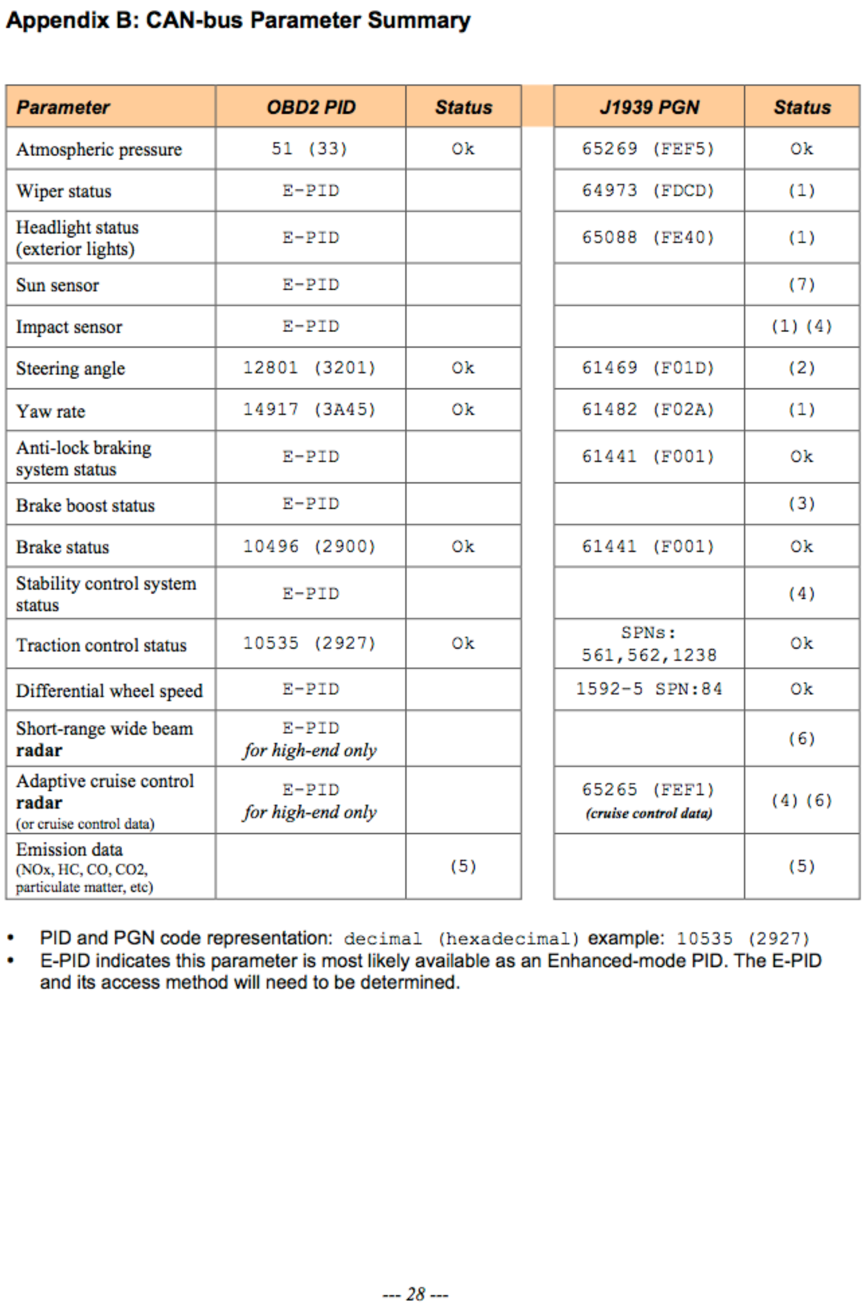
[3] Salt usage data was taken from MN/DOT's Maintenance Management System.
[4] ($25 per air card + $5 for data collection) x 12 months

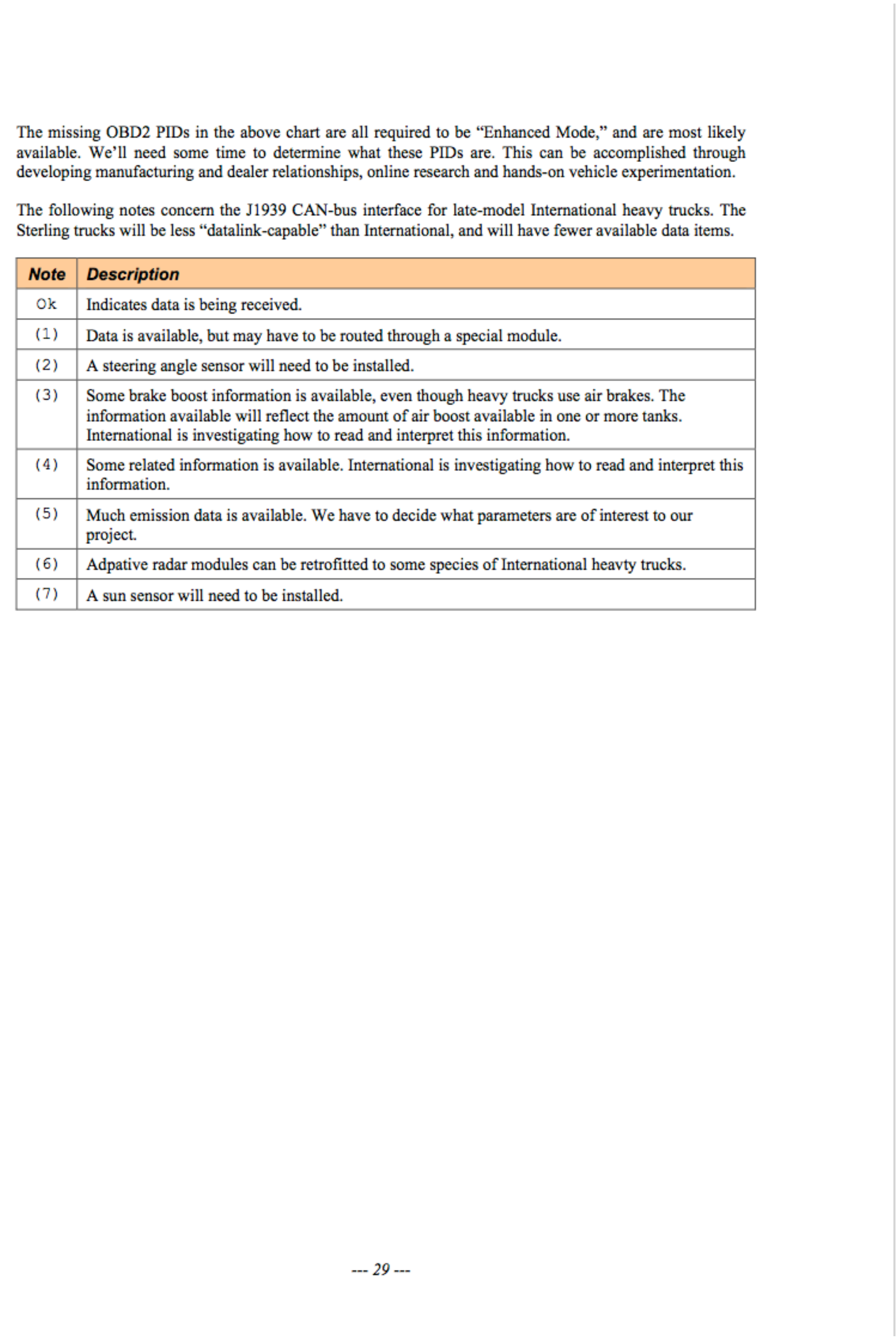


Appendix B: CAN-bus Parameter Summary

Parameter	***OBD2 PID***	***Status***		***J1939 PGN***	***Status***
Atmospheric pressure	`51 (33)`	`Ok`		`65269 (FEF5)`	`Ok`
Wiper status	`E-PID`			`64973 (FDCD)`	`(1)`
Headlight status (exterior lights)	`E-PID`			`65088 (FE40)`	`(1)`
Sun sensor	`E-PID`				`(7)`
Impact sensor	`E-PID`				`(1)(4)`
Steering angle	`12801 (3201)`	`Ok`		`61469 (F01D)`	`(2)`
Yaw rate	`14917 (3A45)`	`Ok`		`61482 (F02A)`	`(1)`
Anti-lock braking system status	`E-PID`			`61441 (F001)`	`Ok`
Brake boost status	`E-PID`				`(3)`
Brake status	`10496 (2900)`	`Ok`		`61441 (F001)`	`Ok`
Stability control system status	`E-PID`				`(4)`
Traction control status	`10535 (2927)`	`Ok`		`SPNs: 561,562,1238`	`Ok`
Differential wheel speed	`E-PID`			`1592-5 SPN:84`	`Ok`
Short-range wide beam **radar**	`E-PID` *for high-end only*				`(6)`
Adaptive cruise control **radar** (or cruise control data)	`E-PID` *for high-end only*			`65265 (FEF1)` ***(cruise control data)***	`(4)(6)`
Emission data (NOx, HC, CO, CO2, particulate matter, etc)		`(5)`			`(5)`

- PID and PGN code representation: `decimal (hexadecimal)` example: `10535 (2927)`
- E-PID indicates this parameter is most likely available as an Enhanced-mode PID. The E-PID and its access method will need to be determined.

--- 28 ---



The missing OBD2 PIDs in the above chart are all required to be "Enhanced Mode," and are most likely available. We'll need some time to determine what these PIDs are. This can be accomplished through developing manufacturing and dealer relationships, online research and hands-on vehicle experimentation.

The following notes concern the J1939 CAN-bus interface for late-model International heavy trucks. The Sterling trucks will be less "datalink-capable" than International, and will have fewer available data items.

Note	***Description***
`Ok`	Indicates data is being received.
`(1)`	Data is available, but may have to be routed through a special module.
`(2)`	A steering angle sensor will need to be installed.
`(3)`	Some brake boost information is available, even though heavy trucks use air brakes. The information available will reflect the amount of air boost available in one or more tanks. International is investigating how to read and interpret this information.
`(4)`	Some related information is available. International is investigating how to read and interpret this information.
`(5)`	Much emission data is available. We have to decide what parameters are of interest to our project.
`(6)`	Adpative radar modules can be retrofitted to some species of International heavty trucks.
`(7)`	A sun sensor will need to be installed.

Appendix C

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ACRONYMS

AVL	Automatic Vehicle Location (tracking system)
CAN	Controller Area Network (CANbus)
DOT	Department of Transportation (State or Municipal)
ESS	Environmental Sensor Station
FHWA	Federal Highway Administration (USDOT)
IMO	ITS Mobile Observations
ITS	Intelligent Transportation System
LDV	Light Duty Vehicle (pickup truck)
MDSS	Maintenance Decision Support System
MMS	Maintenance Management System
NCAR	National Center for Atmospheric Research
OEM	Original Equipment Manufacturer
RDI	Radio Data Interface
RITA	Research and Innovative Technology Administration (USDOT)
RWIS	Road Weather Information System
SAFETEA-LU	Safe, Accountable, Flexible, and Efficient Transportation Equity Act: A Legacy for Users
TOPR	Task Order Proposal Request
VDT	Vehicle Data Translator

1. BACKGROUND

The U.S. Department of Transportation's (USDOT) Federal Highway Administration (FHWA) and Research and Innovative Technology Administration (RITA) have been jointly working to promote safety, mobility and productivity on the nation's surface transportation system by advancing road weather research. Section 5308 of the Safe, Accountable, Flexible, and Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) provides broad direction to the USDOT for the execution of the Road Weather Research and Development Program.

In the project summarized below, the U.S. Department of Transportation's (USDOT) Federal Highway Administration (FHWA) Road Weather Management Program (RWMP) desired to demonstrate how weather, road condition, and related vehicle data may be collected, transmitted, processed, and used for decision making as part of the Intelligent Transportation System (ITS) Mobile Observations (IMO) program[1].

Ultimately, decision-makers will have the benefit of decision support tools that have access to data provided by millions of vehicles through the IMO, Connected Vehicle[2], and other related programs. The use of existing fleet infrastructures and wireless communication technology allowed this prototype project to help determine the procedures and processes required to integrate weather, road condition, and vehicle status data messages into existing programs.

The project also expanded the capabilities of the National Center for Atmospheric Research (NCAR) Vehicle Data Translator (VDT), which incorporates vehicle-based measurements of the road and surrounding atmosphere with other, more traditional weather data sources, to create road and atmospheric hazard products for a variety of users. Additionally, this project featured the integration of mobile weather and road condition data into the FHWA's *Clarus* system. *Clarus*, operated by Mixon Hill Inc., currently collects weather and road condition data from stationary sensors across the U.S. and parts of Canada, and then makes the data available over the Internet with text- and graphics-based retrieval and visualization systems.

2. PROJECT GOALS

Interstate 80 is a major east-west interstate corridor through Nevada, and is a major economic freight and traveler corridor which can better service the public through improved and coordinated maintenance and traveler information services. The I-80 Coalition, currently including California, Nevada, Utah, and Wyoming, exists to (1) establish institutional structure for coordinating operations on I-80 in the western states; (2) aggregate weather conditions information from multiple sources; (3) identify traffic data collection capabilities and share information with other agencies; (4) establish existing capabilities and near-term enhancements to identify specific continuity issues; and (5) research innovative practices from other areas of the country facing similar challenges.

The Nevada Department of Transportation (NDOT), in collaboration with the University of Nevada, Reno (UNR) and National Center for Atmospheric Research (NCAR), was selected by

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[1] The IMO is a multimodal initiative to enable wireless communications among vehicles, the infrastructure, and passengers' personal communications devices. It will enhance Americans' safety, mobility and quality of life, while helping to reduce the environmental impact of surface transportation.

[2] The Connected Vehicle program is an FHWA program working to develop advanced wireless communications systems and onboard sensors and computing systems to identify threats and hazards on the roadway and to communicate this information to other vehicles and infrastructure to increase safety and level of service.

the FHWA to participate in a demonstration IMO project. The main project goal was to develop a prototype IMO system for Nevada that addressed two of NDOT's critical needs:

1. ***Improved system-wide performance monitoring and measurement methods and tools***. The Nevada IMO (NIMO) project uses on-vehicle instrumentation to dynamically gather near-real-time localized weather, road condition, material usage, and vehicle-related data that will be used to gauge road conditions and better inform safety processes (such as chain controls) by providing this data to supervisors and operators through mediums such as *Clarus*.
2. ***Improving Freeway/Highway Maintenance Operations and Equipment Maintenance***. Near-real-time weather, vehicle, and road condition data that will be used by NDOT personnel to improve highway maintenance operations both in terms of increased level of service and cost savings through applications such as Maintenance and Decision Support System (MDSS) and a Maintenance Management System (MMS).

3. RESULTS

Results of the project will be presented in three thematic groups:

3.1 Vehicles and Routes
3.2 Data
3.3 Applications

3.1. Vehicles and Routes

NDOT was able to supply 20 vehicles, including 11 Peterbilt snowplow trucks (model year 2007 or 2009) and 9 Ford light duty vehicles (LDV, model years 2001-2008 F250 and F450) in the Elko and Reno areas for this project. During winter, NDOT operates these trucks regularly along the I-80 corridor around Reno and Elko, as well as adjoining roads within approximately 70-90 miles from I-80. In summer, NDOT uses the same plow trucks, converted for summer maintenance activities, as well as use the light duty vehicles in the Elko and Reno areas.

Proposed Deliverables for 3.1:

1. Use a UNR-owned vehicle as a prototype. Install instruments (OBD, Weather, etc.) and report data online.
2. 20 NDOT vehicles operational (participating in data gathering and telemetry).
   a) Operational using existing 800 MHz EDACS (Enhanced Digital Access Communications System) radio system for data telemetry
   b) Test Open Sky 700 MHz radio system for future implementation
   c) Investigate transitioning of data reporting path from the UNR network server system to incorporation into the NDOT RWIS system.

Actual Deliverables for 3.1

1. In order to bring the first vehicle online NDOT, UNR and NCAR identified instruments capable of collecting, logging, and transmitting the weather, road condition, and vehicle-related data while mounted and operating on a mobile vehicle. We selected a rugged, PC-104 single board computer (SBC) to serve as the "brain" of the system and developed custom client software that runs on the PC-104 and collects the data from the instruments, logs the data, processes and aggregates it, and then

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transmits it using an on-board EDACS radio through the EDACS radio network to a central server (Figure 1).

The system requirements identified included:

- Ability to operate in harsh winter and summer road conditions.
- Ability to gather spatially and temporally tagged localized weather, road condition and vehicle-related (CANbus) data.
- Ability to deliver the data to a central server, live, or with a maximum 5-minute delay.
- Ability to log the data at higher temporal rate to on-board, non-volatile storage for later retrieval and detailed analysis by the FHWA during the pilot phase of the project.
- Ability to withstand frequent, unexpected loss of power without corrupting data.
- Ability to have its operation configurable without needing to be recompiled.
- Ability to operate autonomously and transparently to the vehicle operator.

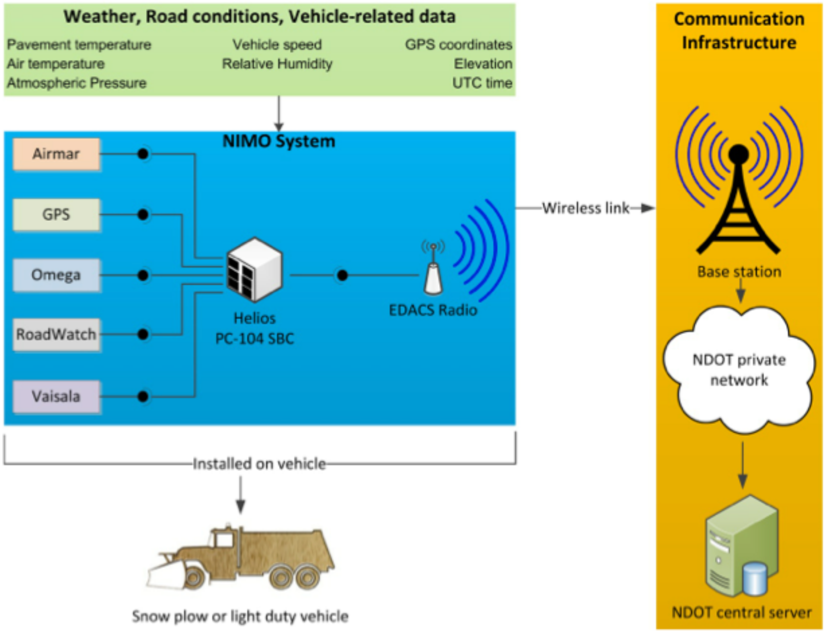

Figure 1. Data collection and delivery to central server (CANbus not shown).

In addition to the PC-104 computer and EDACS radio, the other major system components included the instrumentation used to perform temperature, humidity, pressure, vehicle speed, location and CANbus measurements: i.e., the Aimar, GPS, Omega, RoadWatch, Vaisala, OBD Scan Tool, and Netway instruments.

The Helios PC-104 single board computer, shown in Figure 2, is manufactured by Diamond Systems Corporation. It uses a Vortex CPU operating at 800 MHz and 256 MB of DRAM soldered on-board. The Helios utilizes an internal, 32GB IDE solid state hard drive to store the operating system, the NIMO program, and the collected data.

Figure 2. Helios single board computer.

The EDACS radio (Figure 3), models 500M, 725M, and M7300, manufactured by Harris Corporation, M/A-COM, or Tyco/Ericson, provides both voice and data communication capabilities. The radio transmits data via the EDACS RDI (Radio Data Interface) radio communication protocol using the trunked EDACS radio network installed statewide.

Figure 3. EDACS radio.

The Airmar instrument (Figure 4), model LB150 Ultrasonic Weather Station Instrument, is a land-based version of their marine weather instrument. The measurements obtained from this instrument pertinent to our project are: date, time, data status, latitude, longitude, ground speed, altitude, air temperature, atmospheric pressure, and humidity. Additional data such as accelerations and wind speed are also available, but not of present interest to the project.

Figure 4. Airmar device.

The GPS 16x HVS unit (Figure 5) manufactured by Garmin is configured to report two National Marine Electronics Association (NMEA) data sentences, (1) $GPRMC and (2) $GPGGA. The data parameters in the two NMEA sentences pertinent to our project are: date, time, data status, latitude, longitude, ground speed, and altitude.

Figure 5. Garmin GPS unit.

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The Omega Engineering OM-CP-ULTRASHOCK-50 device (Figure 6) measures air temperature, humidity, and atmospheric pressure. Its data is encoded with a proprietary encoding algorithm.

Figure 6. Omega unit.

The RoadWatch SS Fahrenheit Sensor (Figure 7), part number 849-0100-002, is manufactured by Commercial Vehicle Group and measures air temperature and road surface temperature.

Figure 7. RoadWatch device.

The Surface Patrol HD Pavement Temperature and Humidity Sensor DSP211 (Figure 8), manufactured by Vaisala Inc. measures air temperature, pavement temperature, and relative humidity.

Figure 8. Vaisala device.

The OBD scan tool OBD All-In-One Serial (Figure 9), is an ELM-based device, manufactured by OBD Diagnostics, Inc and interfaces to the plow trucks J1939 CANbus. It is also useable for low-speed OBD CANbus networks.

Figure 9. J1939 scan tool.

The Netway 84 device (Figure 10) is manufactured by Smart Engineering Tools, Inc. and interfaces to the light duty vehicle OBD CANbus.

Figure 10. Netway 84 OBD device.

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Figure 1: A complete AT500 installation, as seen from the passenger side.

Figure 2: A complete AT500 installation, as seen from the operator's side.

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Table 1. Summary of the 21 vehicles being used in the NIMO project.

	Vehicle Description	Vehicle ID	Description	Assigned Area
0	1999 GMC Suburban	56367	UNR prototype	UNR
1	2009 Peterbilt 367	3319	Snowplow/Sander	Reno
2	2009 Peterbilt 367	3320	Snowplow/Sander	Reno
3	2009 Peterbilt 357	0702	Snowplow/Sander	Lovelock
4	2009 Peterbilt 367	0682	Snowplow/Sander	Elko
5	2009 Peterbilt 367	0684	Snowplow/Sander	Wells
6	2009 Peterbilt 367	0706	Snowplow/Sander	Wendover
7	2009 Peterbilt 367	0752	Snowplow/Sander	Wendover
8	2009 Peterbilt 357	0671	Snowplow/Sander	Elko
9	2007 Peterbilt 357	1327	Snowplow/Sander	Reno
10	2007 Peterbilt 357	0339	Snowplow/Sander	Fernley
11	2009 Peterbilt 367	0707	Snowplow/Sander	Gardnerville
12	2007 Ford F450	1856	Dump Truck	Reno
13	2002 Ford F450	0556	Dump Truck	Reno
14	2007 Ford F450	1826	Crew	Elko
15	2001 Ford F450	0156	Crew	Elko
16	2002 Ford F450	0553	Single	Elko
17	2008 Ford F250	0242	Pickup	Reno
18	2008 Ford F450	3216	Single	Elko
19	2006 Ford F450	1828	Crew	Elko
20	2008 Ford F250	2165	Crew	Elko

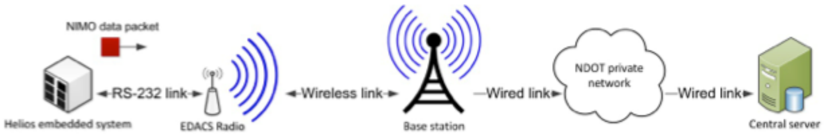


Figure 11. Helios embedded system-to-central server communication links.

3.2. Data

In order to limit the burden on the statewide EDACS radio system, the minimum transmission interval for any given vehicle was set to 5 minutes. Each data packet is also limited to approximately 500 bytes (a limitation of the EDACS system). Because the amount of collected data far exceeded the maximum packet size, only a subset of collected (logged onboard the vehicle) data was transmitted. The transmitted subset is adjustable and consists of high-priority data. It is a representative sampling of the collected data, and provides enough information for meaningful near-real-time analysis by NCAR and end-users at NDOT to gauge road conditions and make road maintenance decisions. Table 2 summarizes the current 500 byte transmitted data packages used in the snow plow and light duty vehicles.

The superset of collected data is available (after manual retrieval from the vehicles) to NCAR analysis and possible assimilation into road weather models and applications. The storing of this data was accomplished using an internal solid state drive that is part of the NIMO hardware. Additionally, we opted for mirroring the data to an external USB flash disk that is easily periodically swapped and delivered to UNR by the NDOT vehicle maintenance crews. We then post the data from the flash disks to a website from which NCAR downloads the data for study.

Table 2. Typical transmitted 500 byte data packages (for the two basic vehicle types).

Parameter	Number of Measurements per 5-min Data Package	
	Snow Plow	**Light Duty**
Air Temperature (Vaisala, Omega, Airmar)	5	5
Air Temperature (Road Watch)	5	5
Air Temperature (CANBus)	5	5
Road Surface Temperature (Road Watch, Vaisala)	30	30
Air Pressure (Omega, Airmar)	5	5
Air Pressure (CANBus)	5	5
Relative Humidity (Vaisala, Omega, Airmar)	5	5
Location, Time, & Vehicle Speed (GPS)	30	30
Vehicle Speed (CANBus)	5	5
CANBUS/OBD Trouble Codes	0	1

The weather-related instruments, the data measured, and nominal reporting intervals are summarized in Table 3. There is some (intentional) overlap in measurements. For example, both the RoadWatch and the Omega devices measure air temperature and humidity. This redundancy allows a comparison of how the devices perform with respect to each other. A more detailed breakdown of collected and telemetered data (on a vehicle-by-vehicle basis) is presented in Appendix A (updated as of 6/22/2012), with a summary of goal achievements in Appendix B.

The data summarized in Appendices A & B are organized by parameter, and sensor type. While not part of the original proposal, a comparison of like data from different sensor types is critical for validating the VDT and for future Connected Vehicle applications. It is envisioned that these applications will rely heavily on the CANbus (OBD and J1939) mobile data as valid sources of weather data (Appendices C & D). A comparison of the CANbus data with the data from high-quality, calibrated vehicle-mounted sensors will be completed after the 2012-2013 winter storm season.

Appendices C & D list the status of the CANbus data for the light duty vehicles and plow trucks respectively. In Appendix C, the broadcast parameters are data that are contained in messages periodically posted on the CANbus by the various ECUs (Engine Control Units). The reading of this data does not require any interaction with the individual ECUs and is, thus, the least intrusive method of gathering CANbus data. The J1979 parameters are data that must be actively polled for from the ECUs. The J1979 parameters conform to the SAE (Society of Automotive Engineers) J1979 standard. The Ford proprietary parameters are data that are available on the CANbus but are unique to Ford vehicles and varies by both make and model year. The location and specification of the proprietary data is not publically available. For the plow trucks, no broadcast or proprietary data was located and, thus, Appendix D only contains parameters that conform to the SAE J1939 standard.

Table 3. Weather-related instruments, the measurements performed, and nominal reporting intervals.

Devices	Time & Location Data	Air Temperature	Pavement Temperature	Relative Humidity	Atmospheric Pressure	Maximum Logging Interval (sec)
Airmar	X	X		X	X	1.0
GPS	X					1.0
Omega		X		X	X	1.0
RoadWatch		X	X			1.0
Vaisala		X	X	X		0.2
CANbus		X			X	1.0

Proposed Deliverables for 3.2:

1. Map of routes where data were collected.

Actual Deliverables for 3.2:

1. As mentioned previously, the I-80 corridor was selected as the route of interest. All vehicles that are part of project are either directly servicing I-80 around Reno and Elko, or are assigned to roadways within 70-90 miles of I-80. A map of routes where data is currently being collected is shown in Figure 12. A section of I-80 in central Nevada is not covered due to the age of plow trucks assigned to this area (none had a J1939 CANbus).

2. The transmitted data delivery effort detailed above and supplemented by information in Appendices A & B has been shown to be reliable. Preliminary analysis shows that data packet transmissions are successful 95-100% of the time. Our hardware is configured to re-try failed transmissions up to 3 times on any given 5-minute interval. Each individual transmission nominally has a ~10% failure rate, which when repeated 4 times, leads to a ~0.01% cumulative failure likelihood for a given packet. When problems are observed, they are usually related to regional or system-wide outages of the EDACS data network that manifest as a 100% failure of all data (not only NIMO data). These types of problems were observed twice during the winter of 2012, each lasting for a few days before the system could be brought back up (beyond the NIMO project team's control). These outages were unrelated to NIMO project operations.

3. As part of this effort, extensive testing of available NDOT vehicles was conducted to identify and locate as many relevant CANbus/OBD parameters as possible on the bus. This was challenging, as many parameters of interest are considered proprietary information by the vehicle manufacturers. Our investigation required close consultation with Smart Engineering Tools, Inc., and extensive scanning of the CANbus using a variety of tools (depending on the particular type of bus). A summary of the results of this survey of parameters is presented in Appendices C and D, sorted by vehicle make/model/year. Many useful parameters have been identified, yet other parameters of interest (such as windshield wiper status) have remained elusive thus far. We can surmise that items such as windshield wiper status and headlight status are not available on the CANbus for the F450 vehicles included in this study.

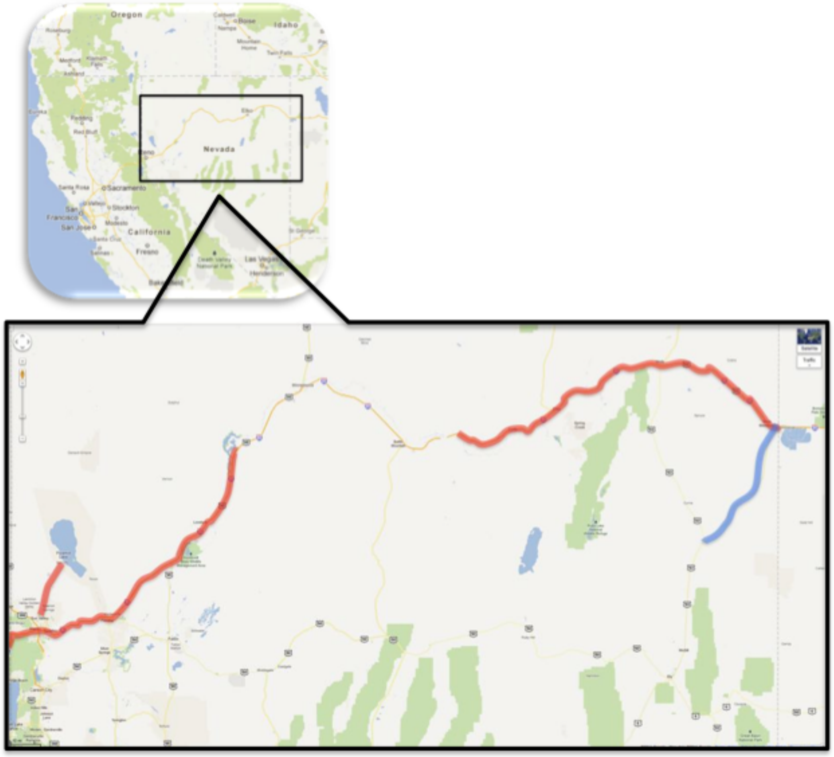


Figure 12. Map of road coverage across I-80 corridor in Nevada.

3.3. Applications

The inclusion of mobile data is providing NDOT with a unique and dynamic source of real-time road condition information that can one day be shared with the traveling public, freight drivers/dispatchers, and transportation/public safety agencies. At the outset of the project, two potential applications were identified: MDSS and MMS. As the project progressed, a third application was identified: transmission of vehicle DTC (diagnostic trouble codes) for equipment maintenance.

3.3.1. MDSS

At the outset of the project, although the basic technology had already been demonstrated, the time required to get all 20 of the NIMO vehicles fully installed and functioning was underestimated. This, combined with a shift in priorities towards developing OBD scanning capabilities, resulted in limited progress towards implementing an MDSS capability. However, the advances were significant in several ways. First, this project produced a pilot study group of 20 instrumented and networked vehicles, ready for further testing in MMS and MDSS applications. Even more significantly, prior to this project, NDOT had not fully investigated the requirements of a fully operational MDSS system. As a direct result of this project, NDOT has gained a much better understanding of the hardware, software, and labor (direct and indirect), that is required to both implement and support a MDSS. The collaboration, as a direct result of this project, with MN/DOT has also helped considerably. A key milestone that was identified for implementing an MDSS is the need for NDOT to first further develop its MMS capability (see below).

The lack of an existing AVL system was also identified as a major impediment. Commercial AVL systems (e.g. Iwapi, AmeriTrak, Telogis, etc.) were examined, but all of them utilized cellular modems as their primary data telemetry mechanism. The lack of cellular coverage in much of rural Nevada and the strong desire to avoid reoccurring monthly costs, led to the development of the PC-104 system described earlier. The system developed is currently serving as the prototype AVL for NDOT and makes use of the existing statewide radio network infrastructure.

The final impediment identified was the inability to test the VDT (Vehicle Data Translator) at NCAR. The mild winter coupled with the NIMO vehicle installation delays severely limited the amount of data that was accessible to NCAR and, as a result, the VDT could not be thoroughly vetted and tested.

Proposed Deliverables for 3.3.1:

1. Report highlighting the savings of delay costs, the number of weather-related crashes and results from formal interviews with major trucking companies who use the I-80 Corridor.

Actual Deliverables for 3.3.1:

1. The hardware infrastructure (20 vehicles) installed is serving as an excellent basis for gathering MMS (and eventually MDSS) data, and applications of the equipment and data will be further developed for the 2012-13 winter season. No report on MDSS cost savings was able to be generated for the numerous reasons outlined above. The proposed deliverable was overly-ambitious in that NDOT does not have an (expensive and time-consuming to implement) functioning MDSS system and does not currently have a means to pass the mobile data to a Traveller Information System (although advances towards both were achieved in this project). Additionally, the mild winter did not allow the collection of meaningful mobile data in significant amounts. Thus, it was not possible to determine the cost savings to commercial carriers. Through the efforts of the I-80 coalition, two meetings have been held with commercial carriers (FedEx, Walmart and C.R. England).

Relevant Outcomes to NIMO Project:

1. Although we were not able to quantify cost savings of an MDSS, such studies have been done elsewhere in the past. Showing that mobile data leads to cost savings should greatly help the broader dissemination of the VDT to other states. In lieu of focusing on this outcome (which we were not well-positioned to pursue, in hindsight), we instead directed our focus in different application directions discussed below.

3.3.2. MMS

NDOT currently uses a "homegrown" version of a Maintenance Management System (MMS). Materials usage is tracked and entered into a database by hand and is a very time-intensive end-of-shift task completed by the drivers, that is considered a "rough approximation" of material usage at best. As a result of this project, the NIMO mobile data, which includes GPS location data, will be used to automate much of this work, virtually eliminating the need for plow truck drivers to manually enter truck locations, application rates, equipment hours, and outcomes, etc. The ability of an automated mobile data collection system to record and populate NDOT's MMS will substantially reduce labor costs and increase accuracy by eliminating manual data entry, and get storm fighters home sooner and better rested to start their next shift of storm fighting. Depending on the Winter Severity in Nevada, an automated mobile data collection system could save NDOT as much as $250,000 per winter in direct labor costs.

The time required to get the NIMO hardware installed into the vehicles and functioning was underestimated. This, combined with a shift in focus (towards studying OBD more carefully than originally intended), resulted in only minor progress towards integrating the mobile data into the existing MMS (thus far). Additionally, it was assumed that interfacing to the spreader controllers was all that was necessary to collect data from the spreaders. However, the spreaders themselves are not instrumented and have not been calibrated, both of which are necessary before application rates can be determined. Thus, instrumentation and calibration will take place during the summer 2012, followed by integration into the MMS system thereafter (fall 2012).

Proposed Deliverables for 3.3.2:

1. Report highlighting how mobile data has led to (a) cost savings and (b) other operational benefits.

Actual Deliverables for 3.3.2:

1. As above with MDSS, no report was generated. The hardware infrastructure installed in 20 vehicles is serving as an excellent basis for gathering MMS data, and is expected to be deployed for the 2012-13 winter season.

Relevant Outcomes to NIMO Project:

1. The effective use of mobile observations can be greatly enhanced if plow drivers "buy into" the NIMO project and see a tangible benefit. Making their end-of-shift paperwork easier is one avenue for accomplishing this.

3.3.3. DTC—Diagnostic Trouble Codes

Diagnostic Trouble Codes (DTC) available on the vehicle's OBD CANbus can readily be scanned and reported to equipment maintenance personnel to help alert them to vehicle maintenance needs and even help with remote diagnosis of vehicle problems. As a result of shifting focus towards maximizing the utility of vehicle OBD data, this potential application emerged. Several consultations with equipment division personnel ensued, leading to growing interest from them for further development and application of this capability.

Proposed Deliverables for 3.3.3:

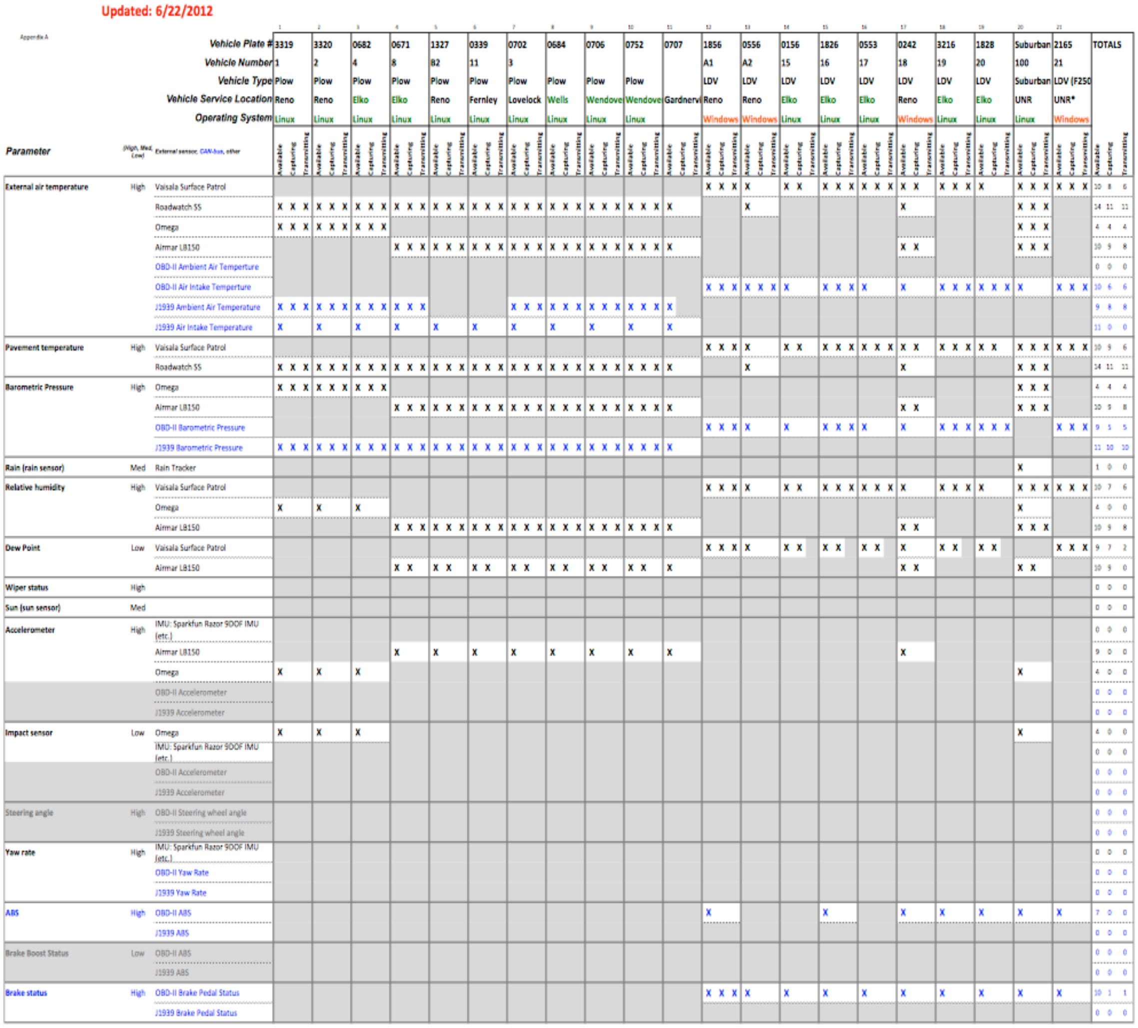
1. None (new application).

Actual Deliverables for 3.3.3:

1. Nine light duty vehicles with OBD systems have been instrumented and pending software updates to be completed this summer, will be reporting DTC information in near-real-time, with data summarized and made available to users (maintenance supervisors and technicians) using a web-page interface. The more recent (2009+) snow plows show signs (based on initial tests) that some DTC information may also be available from snow plows. The DTC's are also being incorporated into the VDT as an added non-weather related feature since the VDT graphical interface is envisioned to be the primary interface for the shift supervisors.

Relevant Outcomes to NIMO Project:

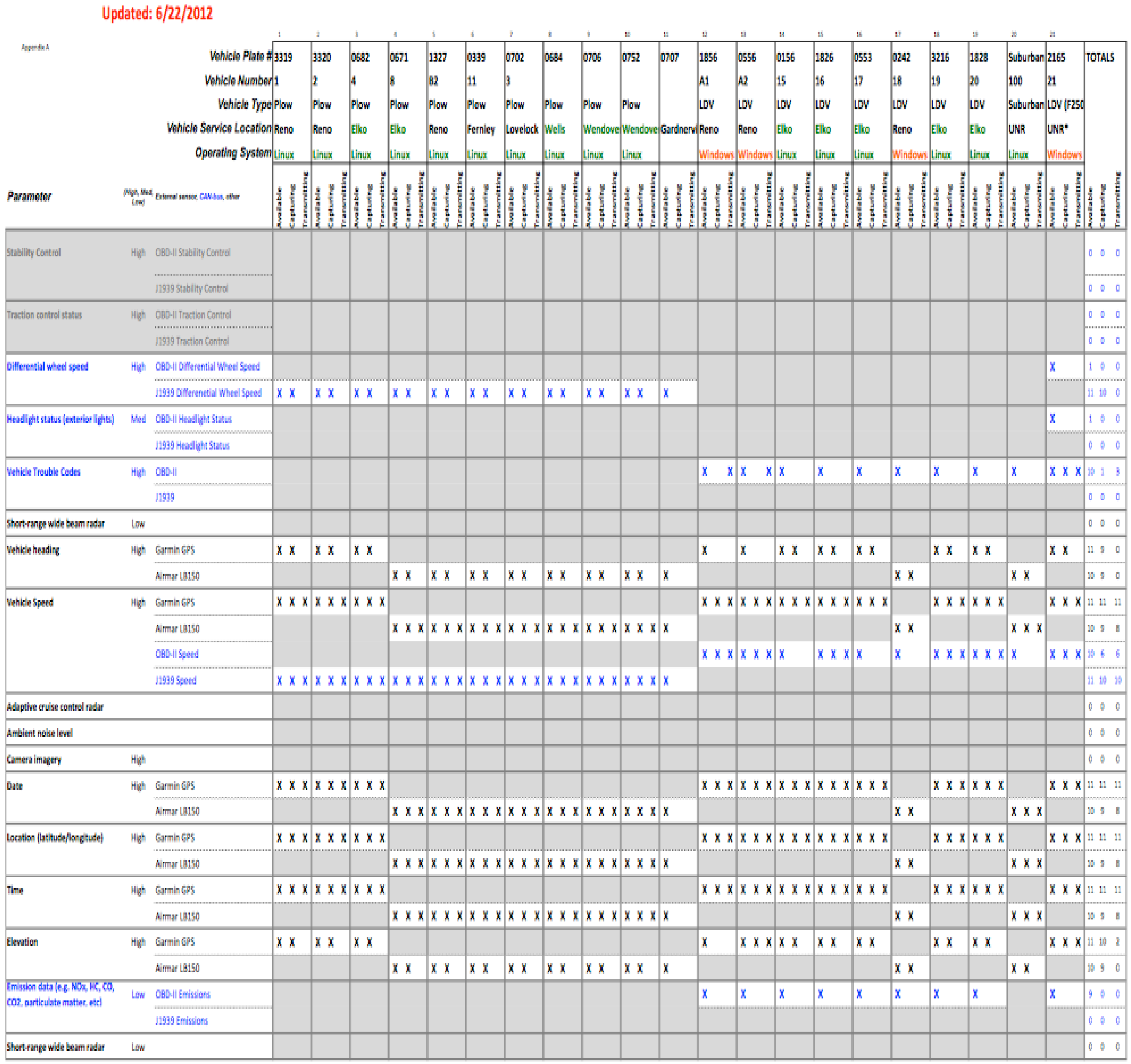
1. The effective use of mobile observations can be greatly enhanced if plow drivers and vehicle maintenance personnel "buy into" the NIMO project and see a tangible benefit. This is one avenue for accomplishing that. Because this is a relatively new concept at NDOT, it is expected that the implementation of this will be "evolutionary" in nature, where user needs and hardware capabilities evolve as ideas emerge and are attempted.
2. Our extensive investigations with OBD and J1939 CANbus data has shown that a lack of a standardized CANbus configuration may severely impact the development and adoption of the VDT and other Connected Vehicle applications. CANbus configurations vary among manufacturers, makes, and model years. For the 20 vehicles used in this project, 9 different CANbus configurations were encountered and each required a customized version of the software. Unless a standardized CANbus standard can be arrived at and adopted for weather and safety-related data, widespread collection of CANbus data may not be feasible.



Updated: 6/22/2012

Appendix A

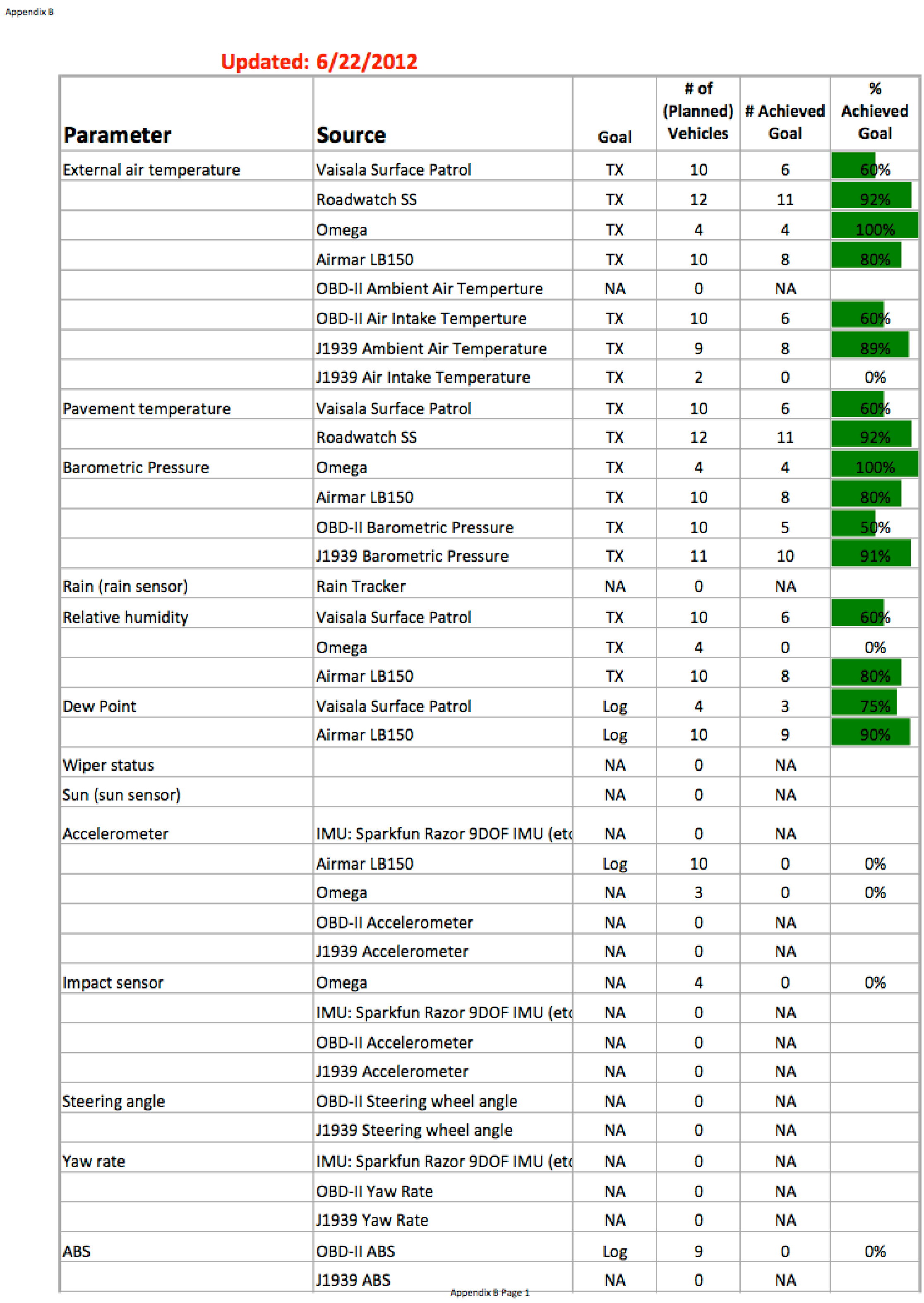
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21			
		Vehicle Plate #	3319	3320	0682	0671	1327	0339	0702	0684	0706	0752	0707	1856	0556	0156	1826	0553	0242	3216	1828	Suburban	2165	TOTALS		
		Vehicle Number	1	2	4	8	B2	11	3					A1	A2	15	16	17	18	19	20	100	21			
		Vehicle Type	Plow	Plow	Plow	Plow	Plow	Plow	Plow	Plow	Plow	Plow		LDV	LDV	LDV	LDV	LDV	LDV	LDV	LDV	Suburban	LDV (F250			
		Vehicle Service Location	Reno	Reno	Elko	Elko	Reno	Fernley	Lovelock	Wells	Wendove	Wendove	Gardnervi	Reno	Reno	Elko	Elko	Elko	Reno	Elko	Elko	UNR	UNR*			
		Operating System	Linux	Linux	Linux	Linux	Linux	Linux	Linux	Linux	Linux	Linux		Windows	Windows	Linux	Linux	Linux	Windows	Linux	Linux	Linux	Windows			
Parameter	(High, Med, Low)	External sensor, CAN-bus, other	Available Capturing Transmitting	Available Capturing Transmitting	Available Capturing Transmitting	Available Capturing Transmitting	Available Capturing Transmitting	Available Capturing Transmitting	Available Capturing Transmitting	Available Capturing Transmitting	Available Capturing Transmitting	Available Capturing Transmitting	Available Capturing Transmitting	Available Capturing Transmitting	Available Capturing Transmitting	Available Capturing Transmitting	Available Capturing Transmitting	Available Capturing Transmitting	Available Capturing Transmitting	Available Capturing Transmitting	Available Capturing Transmitting	Available Capturing Transmitting	Available Capturing Transmitting	Available	Capturing	Transmitting
External air temperature	High	Vaisala Surface Patrol												X X X	X	X X	X X X	X X X	X X	X X X	X	X X X	X X X	10	8	6
		Roadwatch SS	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X		X				X			X X X		14	11	11
		Omega	X X X	X X X	X X X																	X X X		4	4	4
		Airmar LB150				X X X	X X X	X X X	X X X	X X X	X X X	X X X	X						X X			X X X		10	9	8
		OBD-II Ambient Air Temperture																						0	0	0
		OBD-II Air Intake Temperture												X X X	X X X	X	X X X	X	X	X X X	X X X	X	X X X	10	6	6
		J1939 Ambient Air Temperature	X X X	X X X	X X X	X X X			X X X	X X X	X X X	X X X	X											9	8	8
		J1939 Air Intake Temperature	X	X	X	X	X	X	X	X	X	X	X											11	0	0
Pavement temperature	High	Vaisala Surface Patrol												X X X	X	X X	X X X	X X X	X X	X X X	X X	X X X	X X X	10	9	6
		Roadwatch SS	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X		X				X			X X X		14	11	11
Barometric Pressure	High	Omega	X X X	X X X	X X X																	X X X		4	4	4
		Airmar LB150				X X X	X X X	X X X	X X X	X X X	X X X	X X X	X						X X			X X X		10	9	8
		OBD-II Barometric Pressure												X X X	X	X	X X X	X	X	X X X	X X X		X X X	9	5	5
		J1939 Barometric Pressure	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X X X	X											11	10	10
Rain (rain sensor)	Med	Rain Tracker																				X		1	0	0
Relative humidity	High	Vaisala Surface Patrol												X X X	X	X X	X X X	X X X	X	X X X	X	X X X	X X X	10	7	6
		Omega	X	X	X																	X		4	0	0
		Airmar LB150				X X X	X X X	X X X	X X X	X X X	X X X	X X X	X						X X			X X X		10	9	8
Dew Point	Low	Vaisala Surface Patrol												X X X	X	X X	X X	X X	X	X X	X X		X X X	9	7	2
		Airmar LB150				X X	X X	X X	X X	X X	X X	X X	X						X X			X X		10	9	0
Wiper status	High																							0	0	0
Sun (sun sensor)	Med																							0	0	0
Accelerometer	High	IMU: Sparkfun Razor 9DOF IMU (etc.)																						0	0	0
		Airmar LB150				X	X	X	X	X	X	X	X						X					9	0	0
		Omega	X	X	X																	X		4	0	0
		OBD-II Accelerometer																						0	0	0
		J1939 Accelerometer																						0	0	0
Impact sensor	Low	Omega	X	X	X																	X		4	0	0
		IMU: Sparkfun Razor 9DOF IMU (etc.)																						0	0	0
		OBD-II Accelerometer																						0	0	0
		J1939 Accelerometer																						0	0	0
Steering angle	High	OBD-II Steering wheel angle																						0	0	0
		J1939 Steering wheel angle																						0	0	0
Yaw rate	High	IMU: Sparkfun Razor 9DOF IMU (etc.)																						0	0	0
		OBD-II Yaw Rate																						0	0	0
		J1939 Yaw Rate																						0	0	0
ABS	High	OBD-II ABS												X			X		X	X	X	X	X	7	0	0
		J1939 ABS																						0	0	0
Brake Boost Status	Low	OBD-II ABS																						0	0	0
		J1939 ABS																						0	0	0
Brake status	High	OBD-II Brake Pedal Status												X X X	X	X	X	X	X	X	X	X	X	10	1	1
		J1939 Brake Pedal Status																						0	0	0



Updated: 6/22/2012

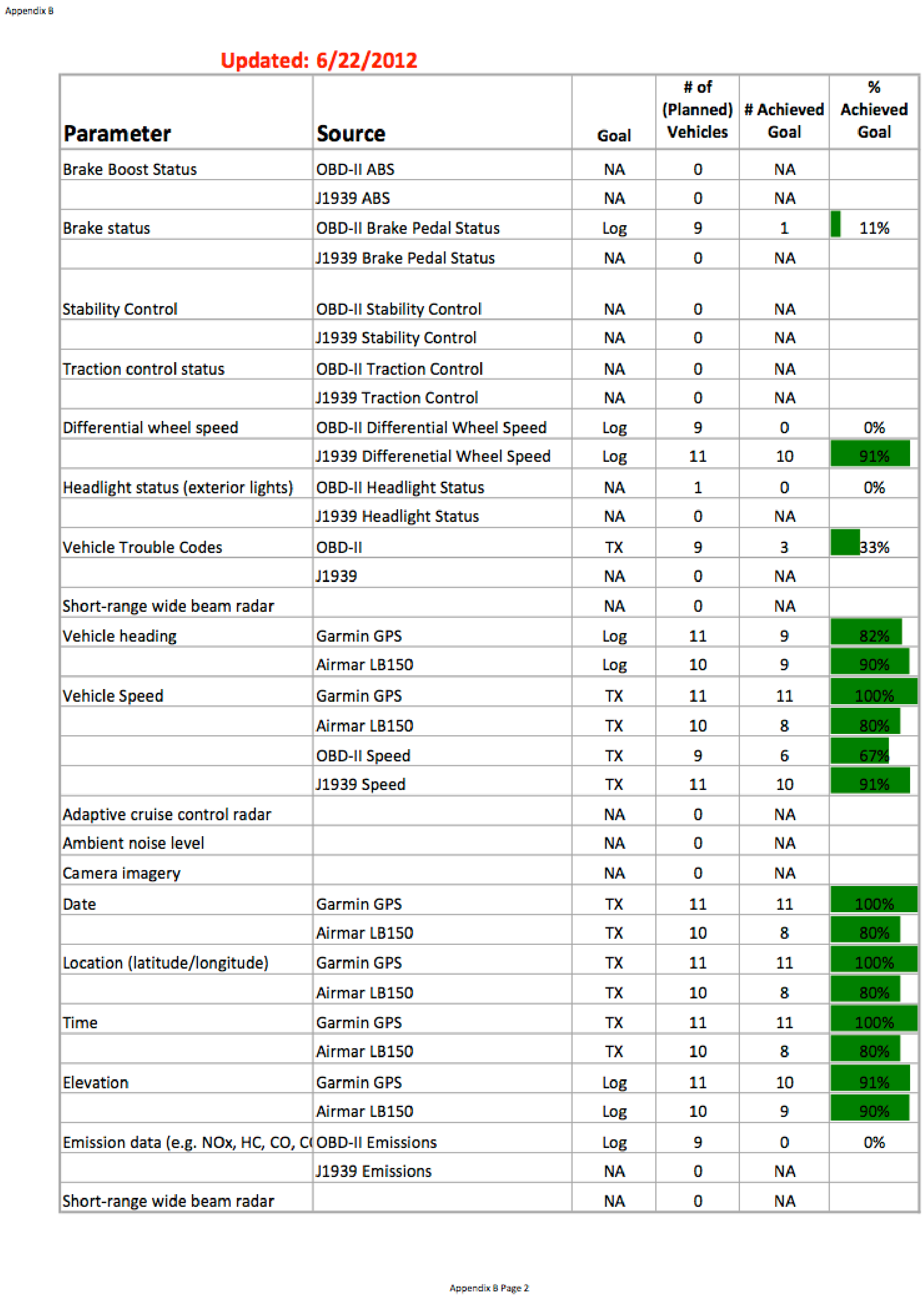
Appendix A

			1			2			3			4			5			6			7			8			9			10			11			12			13			14			15			16			17			18			19			20			21					
		Vehicle Plate #	3319			3320			0682			0671			1327			0339			0702			0684			0706			0752			0707			1856			0556			0156			1826			0553			0242			3216			1828			Suburban			2165			TOTALS		
		Vehicle Number	1			2			4			8			B2			11			3															A1			A2			15			16			17			18			19			20			100			21					
		Vehicle Type	Plow			Plow			Plow			Plow			Plow			Plow			Plow			Plow			Plow			Plow						LDV			LDV			LDV			LDV			LDV			LDV			LDV			LDV			Suburban			LDV (F250					
		Vehicle Service Location	Reno			Reno			Elko			Elko			Reno			Fernley			Lovelock			Wells			Wendove			Wendove			Gardnervi			Reno			Reno			Elko			Elko			Elko			Reno			Elko			Elko			UNR			UNR*					
		Operating System	Linux			Linux			Linux			Linux			Linux			Linux			Linux			Linux			Linux			Linux						Windows			Windows			Linux			Linux			Linux			Windows			Linux			Linux			Linux			Windows					
Parameter	(High, Med, Low)	External sensor, CAN-bus, other	Available	Capturing	Transmitting	Available	Capturing	Transmitting	Available	Capturing	Transmitting	Available	Capturing	Transmitting	Available	Capturing	Transmitting	Available	Capturing	Transmitting	Available	Capturing	Transmitting	Available	Capturing	Transmitting	Available	Capturing	Transmitting	Available	Capturing	Transmitting	Available	Capturing	Transmitting	Available	Capturing	Transmitting	Available	Capturing	Transmitting	Available	Capturing	Transmitting	Available	Capturing	Transmitting	Available	Capturing	Transmitting	Available	Capturing	Transmitting	Available	Capturing	Transmitting	Available	Capturing	Transmitting	Available	Capturing	Transmitting	Available	Capturing	Transmitting	Available	Capturing	Transmitting
Stability Control	High	OBD-II Stability Control																																																															0	0	0
		J1939 Stability Control																																																															0	0	0
Traction control status	High	OBD-II Traction Control																																																															0	0	0
		J1939 Traction Control																																																															0	0	0
Differential wheel speed	High	OBD-II Differential Wheel Speed																																																												X			1	0	0
		J1939 Differenetial Wheel Speed	X	X		X	X		X	X		X	X		X	X		X	X		X	X		X	X		X	X		X	X		X																																	11	10	0
Headlight status (exterior lights)	Med	OBD-II Headlight Status																																																												X			1	0	0
		J1939 Headlight Status																																																															0	0	0
Vehicle Trouble Codes	High	OBD-II																																	X		X	X		X	X			X			X			X			X			X			X			X	X	X	10	1	3
		J1939																																																															0	0	0
Short-range wide beam radar	Low																																																																0	0	0
Vehicle heading	High	Garmin GPS	X	X		X	X		X	X																											X			X			X	X		X	X		X	X					X	X		X	X					X	X		11	9	0
		Airmar LB150										X	X		X	X		X	X		X	X		X	X		X	X		X	X		X																		X	X								X	X					10	9	0
Vehicle Speed	High	Garmin GPS	X	X	X	X	X	X	X	X	X																										X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				X	X	X	X	X	X				X	X	X	11	11	11
		Airmar LB150										X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X																		X	X								X	X	X				10	9	8
		OBD-II Speed																																			X	X	X	X	X	X	X			X	X	X	X			X			X	X	X	X	X	X	X			X	X	X	10	6	6
		J1939 Speed	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X																																	11	10	10
Adaptive cruise control radar																																																																	0	0	0
Ambient noise level																																																																		0	0	0
Camera imagery	High																																																																	0	0	0
Date	High	Garmin GPS	X	X	X	X	X	X	X	X	X																										X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				X	X	X	X	X	X				X	X	X	11	11	11
		Airmar LB150										X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X																		X	X								X	X	X				10	9	8
Location (latitude/longitude)	High	Garmin GPS	X	X	X	X	X	X	X	X	X																										X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				X	X	X	X	X	X				X	X	X	11	11	11
		Airmar LB150										X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X																		X	X								X	X	X				10	9	8
Time	High	Garmin GPS	X	X	X	X	X	X	X	X	X																										X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				X	X	X	X	X	X				X	X	X	11	11	11
		Airmar LB150										X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X																		X	X								X	X	X				10	9	8
Elevation	High	Garmin GPS	X	X		X	X		X	X																											X			X	X	X	X	X		X	X		X	X					X	X		X	X					X	X	X	11	10	2
		Airmar LB150										X	X		X	X		X	X		X	X		X	X		X	X		X	X		X																		X	X								X	X					10	9	0
Emission data (e.g. NOx, HC, CO, CO2, particulate matter, etc)	Low	OBD-II Emissions																																			X			X			X			X			X			X			X			X						X			9	0	0
		J1939 Emissions																																																																0	0	0
Short-range wide beam radar	Low																																																																	0	0	0



Updated: 6/22/2012

Parameter	**Source**	**Goal**	**# of (Planned) Vehicles**	**# Achieved Goal**	**% Achieved Goal**
External air temperature	Vaisala Surface Patrol	TX	10	6	60%
	Roadwatch SS	TX	12	11	92%
	Omega	TX	4	4	100%
	Airmar LB150	TX	10	8	80%
	OBD-II Ambient Air Temperture	NA	0	NA	
	OBD-II Air Intake Temperture	TX	10	6	60%
	J1939 Ambient Air Temperature	TX	9	8	89%
	J1939 Air Intake Temperature	TX	2	0	0%
Pavement temperature	Vaisala Surface Patrol	TX	10	6	60%
	Roadwatch SS	TX	12	11	92%
Barometric Pressure	Omega	TX	4	4	100%
	Airmar LB150	TX	10	8	80%
	OBD-II Barometric Pressure	TX	10	5	50%
	J1939 Barometric Pressure	TX	11	10	91%
Rain (rain sensor)	Rain Tracker	NA	0	NA	
Relative humidity	Vaisala Surface Patrol	TX	10	6	60%
	Omega	TX	4	0	0%
	Airmar LB150	TX	10	8	80%
Dew Point	Vaisala Surface Patrol	Log	4	3	75%
	Airmar LB150	Log	10	9	90%
Wiper status		NA	0	NA	
Sun (sun sensor)		NA	0	NA	
Accelerometer	IMU: Sparkfun Razor 9DOF IMU (etc	NA	0	NA	
	Airmar LB150	Log	10	0	0%
	Omega	NA	3	0	0%
	OBD-II Accelerometer	NA	0	NA	
	J1939 Accelerometer	NA	0	NA	
Impact sensor	Omega	NA	4	0	0%
	IMU: Sparkfun Razor 9DOF IMU (etc	NA	0	NA	
	OBD-II Accelerometer	NA	0	NA	
	J1939 Accelerometer	NA	0	NA	
Steering angle	OBD-II Steering wheel angle	NA	0	NA	
	J1939 Steering wheel angle	NA	0	NA	
Yaw rate	IMU: Sparkfun Razor 9DOF IMU (etc	NA	0	NA	
	OBD-II Yaw Rate	NA	0	NA	
	J1939 Yaw Rate	NA	0	NA	
ABS	OBD-II ABS	Log	9	0	0%
	J1939 ABS	NA	0	NA	

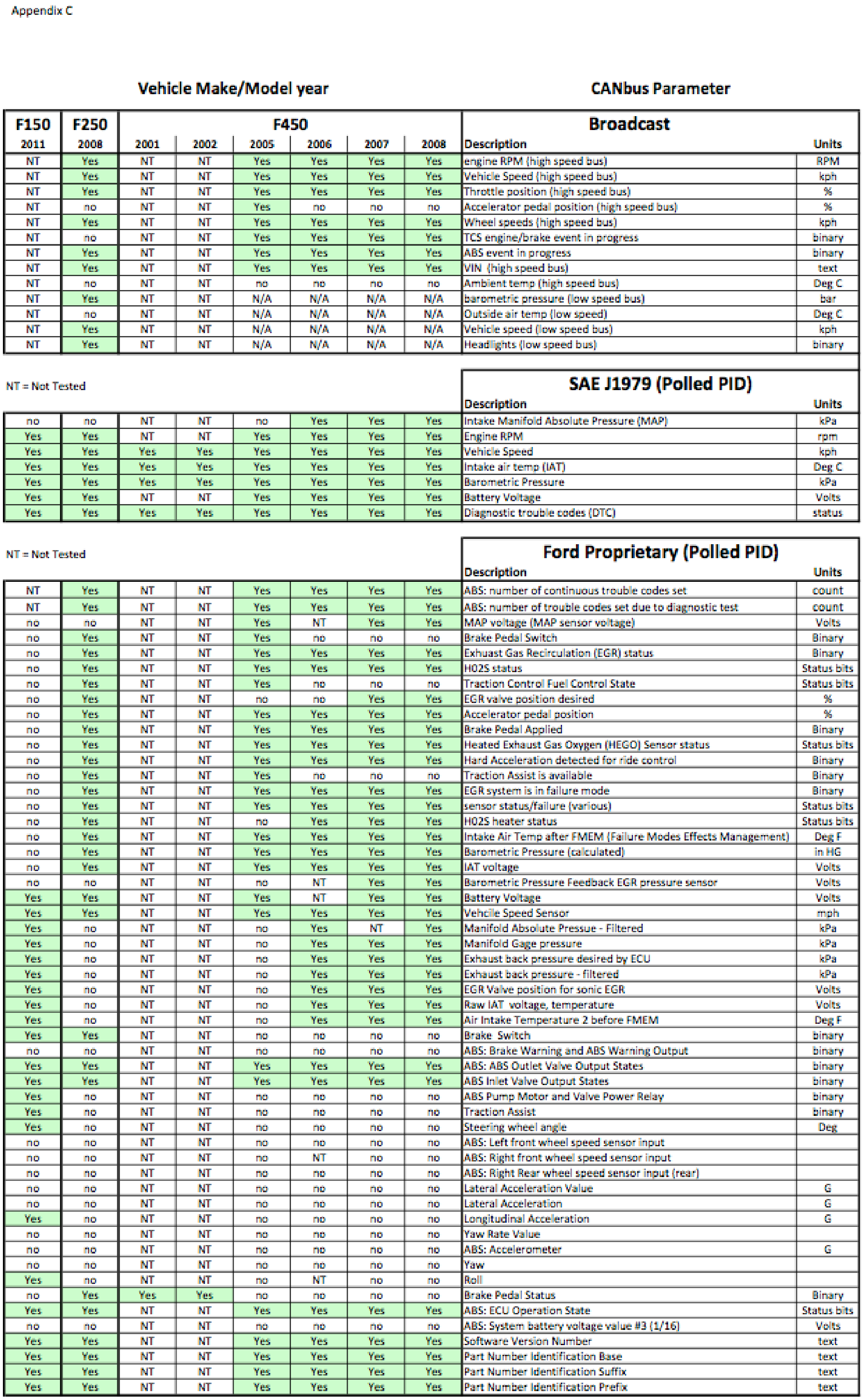


Appendix B

Updated: 6/22/2012

Parameter	Source	Goal	# of (Planned) Vehicles	# Achieved Goal	% Achieved Goal
Brake Boost Status	OBD-II ABS	NA	0	NA	
	J1939 ABS	NA	0	NA	
Brake status	OBD-II Brake Pedal Status	Log	9	1	11%
	J1939 Brake Pedal Status	NA	0	NA	
Stability Control	OBD-II Stability Control	NA	0	NA	
	J1939 Stability Control	NA	0	NA	
Traction control status	OBD-II Traction Control	NA	0	NA	
	J1939 Traction Control	NA	0	NA	
Differential wheel speed	OBD-II Differential Wheel Speed	Log	9	0	0%
	J1939 Differenetial Wheel Speed	Log	11	10	91%
Headlight status (exterior lights)	OBD-II Headlight Status	NA	1	0	0%
	J1939 Headlight Status	NA	0	NA	
Vehicle Trouble Codes	OBD-II	TX	9	3	33%
	J1939	NA	0	NA	
Short-range wide beam radar		NA	0	NA	
Vehicle heading	Garmin GPS	Log	11	9	82%
	Airmar LB150	Log	10	9	90%
Vehicle Speed	Garmin GPS	TX	11	11	100%
	Airmar LB150	TX	10	8	80%
	OBD-II Speed	TX	9	6	67%
	J1939 Speed	TX	11	10	91%
Adaptive cruise control radar		NA	0	NA	
Ambient noise level		NA	0	NA	
Camera imagery		NA	0	NA	
Date	Garmin GPS	TX	11	11	100%
	Airmar LB150	TX	10	8	80%
Location (latitude/longitude)	Garmin GPS	TX	11	11	100%
	Airmar LB150	TX	10	8	80%
Time	Garmin GPS	TX	11	11	100%
	Airmar LB150	TX	10	8	80%
Elevation	Garmin GPS	Log	11	10	91%
	Airmar LB150	Log	10	9	90%
Emission data (e.g. NOx, HC, CO, C	OBD-II Emissions	Log	9	0	0%
	J1939 Emissions	NA	0	NA	
Short-range wide beam radar		NA	0	NA	

Appendix B Page 2



Appendix C

Vehicle Make/Model year

CANbus Parameter

F150	F250	F450						Broadcast	
2011	2008	2001	2002	2005	2006	2007	2008	Description	Units
NT	Yes	NT	NT	Yes	Yes	Yes	Yes	engine RPM (high speed bus)	RPM
NT	Yes	NT	NT	Yes	Yes	Yes	Yes	Vehicle Speed (high speed bus)	kph
NT	Yes	NT	NT	Yes	Yes	Yes	Yes	Throttle position (high speed bus)	%
NT	no	NT	NT	Yes	no	no	no	Accelerator pedal position (high speed bus)	%
NT	Yes	NT	NT	Yes	Yes	Yes	Yes	Wheel speeds (high speed bus)	kph
NT	no	NT	NT	Yes	Yes	Yes	Yes	TCS engine/brake event in progress	binary
NT	Yes	NT	NT	Yes	Yes	Yes	Yes	ABS event in progress	binary
NT	Yes	NT	NT	Yes	Yes	Yes	Yes	VIN (high speed bus)	text
NT	no	NT	NT	no	no	no	no	Ambient temp (high speed bus)	Deg C
NT	Yes	NT	NT	N/A	N/A	N/A	N/A	barometric pressure (low speed bus)	bar
NT	no	NT	NT	N/A	N/A	N/A	N/A	Outside air temp (low speed)	Deg C
NT	Yes	NT	NT	N/A	N/A	N/A	N/A	Vehicle speed (low speed bus)	kph
NT	Yes	NT	NT	N/A	N/A	N/A	N/A	Headlights (low speed bus)	binary

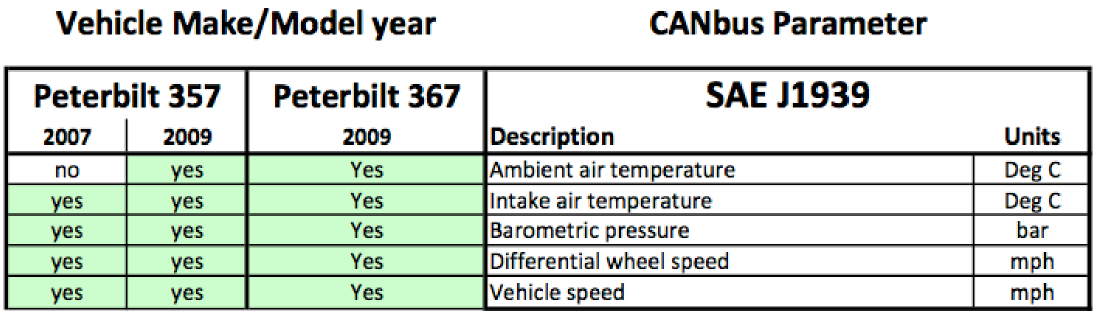
NT = Not Tested

								SAE J1979 (Polled PID)	
								Description	Units
no	no	NT	NT	no	Yes	Yes	Yes	Intake Manifold Absolute Pressure (MAP)	kPa
Yes	Yes	NT	NT	Yes	Yes	Yes	Yes	Engine RPM	rpm
Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Vehicle Speed	kph
Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Intake air temp (IAT)	Deg C
Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Barometric Pressure	kPa
Yes	Yes	NT	NT	Yes	Yes	Yes	Yes	Battery Voltage	Volts
Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Diagnostic trouble codes (DTC)	status

NT = Not Tested

								Ford Proprietary (Polled PID)	
								Description	Units
NT	Yes	NT	NT	Yes	Yes	Yes	Yes	ABS: number of continuous trouble codes set	count
NT	Yes	NT	NT	Yes	Yes	Yes	Yes	ABS: number of trouble codes set due to diagnostic test	count
no	no	NT	NT	Yes	NT	Yes	Yes	MAP voltage (MAP sensor voltage)	Volts
no	Yes	NT	NT	Yes	no	no	no	Brake Pedal Switch	Binary
no	Yes	NT	NT	Yes	Yes	Yes	Yes	Exhuast Gas Recirculation (EGR) status	Binary
no	Yes	NT	NT	Yes	Yes	Yes	Yes	H02S status	Status bits
no	Yes	NT	NT	Yes	no	no	no	Traction Control Fuel Control State	Status bits
no	Yes	NT	NT	no	no	Yes	Yes	EGR valve position desired	%
no	Yes	NT	NT	Yes	Yes	Yes	Yes	Accelerator pedal position	%
no	Yes	NT	NT	Yes	Yes	Yes	Yes	Brake Pedal Applied	Binary
no	Yes	NT	NT	Yes	Yes	Yes	Yes	Heated Exhaust Gas Oxygen (HEGO) Sensor status	Status bits
no	Yes	NT	NT	Yes	Yes	Yes	Yes	Hard Acceleration detected for ride control	Binary
no	Yes	NT	NT	Yes	no	no	no	Traction Assist is available	Binary
no	Yes	NT	NT	Yes	Yes	Yes	Yes	EGR system is in failure mode	Binary
no	Yes	NT	NT	Yes	Yes	Yes	Yes	sensor status/failure (various)	Status bits
no	Yes	NT	NT	no	Yes	Yes	Yes	H02S heater status	Status bits
no	Yes	NT	NT	Yes	Yes	Yes	Yes	Intake Air Temp after FMEM (Failure Modes Effects Management)	Deg F
no	Yes	NT	NT	Yes	Yes	Yes	Yes	Barometric Pressure (calculated)	in HG
no	Yes	NT	NT	Yes	Yes	Yes	Yes	IAT voltage	Volts
no	no	NT	NT	no	NT	Yes	Yes	Barometric Pressure Feedback EGR pressure sensor	Volts
Yes	Yes	NT	NT	Yes	NT	Yes	Yes	Battery Voltage	Volts
Yes	Yes	NT	NT	Yes	Yes	Yes	Yes	Vehcile Speed Sensor	mph
Yes	no	NT	NT	no	Yes	NT	Yes	Manifold Absolute Pressue - Filtered	kPa
Yes	no	NT	NT	no	Yes	Yes	Yes	Manifold Gage pressure	kPa
Yes	no	NT	NT	no	Yes	Yes	Yes	Exhaust back pressure desired by ECU	kPa
Yes	no	NT	NT	no	Yes	Yes	Yes	Exhaust back pressure - filtered	kPa
Yes	no	NT	NT	no	Yes	Yes	Yes	EGR Valve position for sonic EGR	Volts
Yes	no	NT	NT	no	Yes	Yes	Yes	Raw IAT voltage, temperature	Volts
Yes	no	NT	NT	no	Yes	Yes	Yes	Air Intake Temperature 2 before FMEM	Deg F
Yes	Yes	NT	NT	no	no	no	no	Brake Switch	binary
no	no	NT	NT	no	no	no	no	ABS: Brake Warning and ABS Warning Output	binary
Yes	Yes	NT	NT	Yes	Yes	Yes	Yes	ABS: ABS Outlet Valve Output States	binary
Yes	Yes	NT	NT	Yes	Yes	Yes	Yes	ABS Inlet Valve Output States	binary
Yes	no	NT	NT	no	no	no	no	ABS Pump Motor and Valve Power Relay	binary
Yes	no	NT	NT	no	no	no	no	Traction Assist	binary
Yes	no	NT	NT	no	no	no	no	Steering wheel angle	Deg
no	no	NT	NT	no	no	no	no	ABS: Left front wheel speed sensor input	
no	no	NT	NT	no	NT	no	no	ABS: Right front wheel speed sensor input	
no	no	NT	NT	no	no	no	no	ABS: Right Rear wheel speed sensor input (rear)	
no	no	NT	NT	no	no	no	no	Lateral Acceleration Value	G
no	no	NT	NT	no	no	no	no	Lateral Acceleration	G
Yes	no	NT	NT	no	no	no	no	Longitudinal Acceleration	G
no	no	NT	NT	no	no	no	no	Yaw Rate Value	
no	no	NT	NT	no	no	no	no	ABS: Accelerometer	G
no	no	NT	NT	no	no	no	no	Yaw	
Yes	no	NT	NT	no	NT	no	no	Roll	
no	Yes	Yes	Yes	no	no	no	no	Brake Pedal Status	Binary
Yes	Yes	NT	NT	Yes	Yes	Yes	Yes	ABS: ECU Operation State	Status bits
no	no	NT	NT	no	no	no	no	ABS: System battery voltage value #3 (1/16)	Volts
Yes	Yes	NT	NT	Yes	Yes	Yes	Yes	Software Version Number	text
Yes	Yes	NT	NT	Yes	Yes	Yes	Yes	Part Number Identification Base	text
Yes	Yes	NT	NT	Yes	Yes	Yes	Yes	Part Number Identification Suffix	text
Yes	Yes	NT	NT	Yes	Yes	Yes	Yes	Part Number Identification Prefix	text

Appendix D



Vehicle Make/Model year			CANbus Parameter	
Peterbilt 357		**Peterbilt 367**	**SAE J1939**	
2007	**2009**	**2009**	**Description**	**Units**
no	yes	Yes	Ambient air temperature	Deg C
yes	yes	Yes	Intake air temperature	Deg C
yes	yes	Yes	Barometric pressure	bar
yes	yes	Yes	Differential wheel speed	mph
yes	yes	Yes	Vehicle speed	mph

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